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The U.S. Congress in 1977 authorized funding for an "overview environmental impact study," to assess the impacts of population growth and proposed natural resource development on the Flathead River Basin. The conclusions and recommendations based on the five year study are presented.

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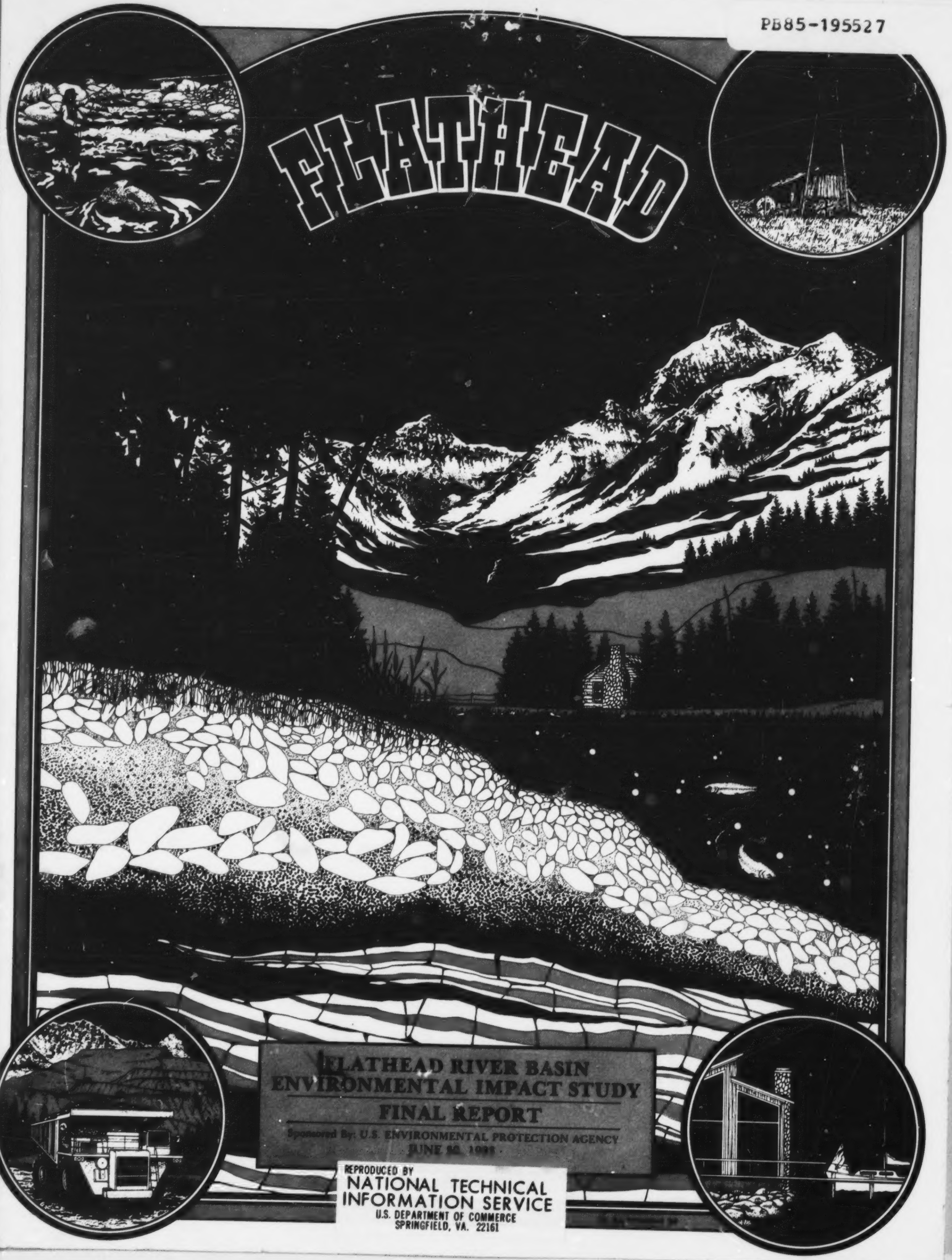

FLATHEAD RIVER BASIN ENVIRONMENTAL IMPACT STUDY

FINAL REPORT

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FINAL REPORT OF THE STEERING COMMITTEE FOR THE FLATHEAD RIVER BASIN ENVIRONMENTAL IMPACT STUDY

June 30, 1983

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The Flathead River Basin Environmental Impact Study owes its success primarily to the support and faith that the people of the Flathead Basin put in the Steering Committee and researchers who worked on the study. The dedication of the Steering Committee members, who accepted the challenge to insure that the study met local needs, who devoted long hours setting study priorities, and who oversaw study progress, has justified that public faith. Special recognition is given to Leland Schoonover who, as the first chairman of the Steering Committee, molded it into a working committee. The support of Governor Ted Schwinden and Roger Williams, former regional administrator for the Environmental Protection Agency, is also appreciated; these men demonstrated their confidence in local people making local decisions. The foresight of State Senator Jean Turnage in seeing the need to establish a permanent commission to look after the resources of the basin is acknowledged. Finally, special recognition is given to Senator Max Baucus who saw the need for the study and, more importantly, insured that the study would be successfully completed.

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RECOMMENDATIONS OF THE STEERING COMMITTEE FOR THE FLATHEAD RIVER BASIN ENVIRONMENTAL IMPACT STUDY

In 1977, the United States Congress authorized funding for "an overview environmental impact study" to assess the impacts of population growth and proposed natural resource development on the Flathead River Basin. The following year, the U.S. Environmental Protection Agency appointed a Steering Committee composed of goverment officials, private citizens, and land managers to direct the Flathead River Basin Environmental Impact Study. The study goal, as set forth by the Steering Committee, was to enhance the quality of life while maintaining a clean and healthful environment, and toward that end the committee has identified priorities, reviewed and authorized specific studies, and overseen the progress of the research. The information generated through the Flathead River Basin Environmental Impact Study has established a baseline of resource conditions against which future changes can be measured and has documented the environmental components that must be maintained to conserve the region's human and natural values.

With the publication of this final report of the Flathead River Basin Envionmental Impact Study, the Steering Committee has completed its task; however, the need to monitor and conserve the integrity of the Flathead Basin environment remains an important public policy concern. The Flathead Basin Commission, a permanent governmental entity established by the 1983 session of the Montana Legislature, will now be responsible to encourage coordination between the various land management jurisdictions throughout the basin. To provide guidance and direction to the Flathead Basin Commission and the public concerned about the basin environment, the Steering Committee has adopted the following conclusions and recommendations based on the findings of the five-year Flathead River Basin Environmental Impact Study. There is no priority to the order of the recommendations.

1. The Flathead River Basin is a complex ecosystem in which Flathead Lake's water quality and biological health are a direct reflection of the land use and development activities occurring in the drainage. *The Steering Committee finds there is a critical need for coordination and monitoring by all levels of government and the private sector responsible for managing the resources of The Flathead Basin.*
2. Land use and development activities occurring on both sides of the border within the Flathead River Basin have the potential to affect the existing high quality environment. *The Steering Committee recommends that Montana work for greater coordination and cooperation with British Columbia concerning resource management and that data and information exchanges continue.*
3. Decisions concerning resource utilization within the Flathead Basin affect both the quality of the environment and the level of economic activity. *The Steering Committee recommends that the opportunity for public involvement be available and that public participation be encouraged regarding major land use and development decisions.*
4. The proposed Cabin Creek coal mine is the largest environmental threat currently facing the basin. *The Steering Committee recommends that the U.S. State Department and the state of Montana call for careful scrutiny of the mine by Canada and British Columbia. The Steering Committee further finds that the mine as presently proposed, with its close proximity to Howell and Cabin Creeks poses the potential for irrevocable harm to the downstream water quality and biological health of The Flathead Lake and River System.*
5. The economy of the basin is primarily comprised of natural resource dependent industries such as tourism, forestry, agriculture and hydro-electric generation. Each of these employment sectors are important to maintaining a sound economy in the basin. *The Steering Committee recommends that all sectors work together to maintain a balance between resource developments in order to insure the continuance of a high quality natural environment.*

6. The value of recreation and maintaining the quality of Flathead Lake and River has conservatively been determined to be in excess of one hundred million dollars per year. *The Steering Committee recommends that this value be considered in determining the benefits to be derived from any land use or development activity which would have the potential to adversely affect the quality of Flathead Lake or The Flathead River System.*

7. The air resources of the basin have been determined to be of excellent quality, except for excessive levels of fugitive dust and woodsmoke found within primarily urban areas. The valley is subject to prolonged inversions which tend to trap and aggravate emissions. *The Steering Committee recommends that air quality monitoring continue in order to avert future problems and to insure that existing air quality standards be met.*

8. The Cabin Creek coal mine as presently proposed will adversely impact the Class I airshed of Glacier National Park, a world biosphere reserve and an international peace park. *The Steering Committee recommends that the U.S. State Department and the State of Montana press for a mine plan which recognizes the protection of a Class I airshed with particular emphasis on SO_2 and particulates. Further, since these impacts would directly impact Glacier National Park, the Steering Committee recommends that the National Park Service continue to monitor the air resources of the park and that a baseline of existing vegetation susceptible to emissions impacts be established.*

9. The geology of the tributary stream basins determines the water quality of the basin. Certain headwater stream basins are poorly buffered from potential adverse impacts caused by acid deposition. *The Steering Committee recommends that these tributary basins be identified and a long-term monitoring program be undertaken.*

10. The water quality of Flathead Lake is changing due to an increase in the amount of phosphorus entering the lake, and that approximately 17% of this phosphorus comes from community sewage and waste disposal facilities. *The Steering Committee recommends that the Montana Department of Health and Environmental Sciences require that community facilities draining into Flathead Lake institute advanced waste water treatment to remove nutrients. The Steering Committee further recommends that primary productivity and the nutrient response of Flathead Lake continue to be monitored.*

11. On-site sewage and waste disposal facilities may also be affecting the quality of Flathead Lake. Nutrient movement has been documented from the Evergreen area into the Flathead River and from an area north of Lakeside into Flathead Lake. *The Steering Committee recommends that detailed on-site soils investigations be made for all individual waste disposal facilities with particular emphasis provided for lakeshores and alluvial soils areas, along water courses, and in high groundwater areas. The Steering Committee further recommends that Evergreen, the Lakeside/Somers area, the area northwest of Polson and other critical developing areas, begin planning to construct community sewage and waste disposal facilities. Further, the Steering Committee finds a need to continue research of nutrient inputs from critical areas such as lakeshores and to better understand the effects that development in these areas is having upon the quality of Flathead Lake.*

12. Mine waste water plans for the proposed Cabin Creek coal mine proposes to rely upon a 50 milligrams per liter total suspended solids discharges standard. This level of sediment is higher than found in any North Fork Flathead River tributary, at any time of the year. Discharges of sediment at other than high water periods would adversely affect the quality of Howell Creek and the North Fork Flathead River. This discharge standard is inconsistent with Montana's A-1 water quality standard for the North Fork of the Flathead River. *The Steering Committee recommends that a discharge standard of 15 milligrams per liter total suspended solids be adopted and that discharges only be permitted during periods of spring run-off.*

13. Sedimentation has a potential to adversely affect stream spawning and rearing habitat as well as contribute to the downstream fertilization of Flathead Lake. *The Steering Committee recommends that monitoring of sediments in tributary streams continue with an emphasis on understanding the effects that these sediments are having on the spawning and rearing of sport fish and aquatic insect production. The Steering Committee further recommends that research be undertaken to gain a better understanding of bedload movement and bank undercutting in the third order and larger streams.*

14. Biological communities of the stream system are strongly influenced by food availability and sediment loading and are cued and segregated by temperature dynamics. *The Steering Committee recommends that monitoring of temperature, organic carbon, and suspended sediments be continued throughout the drainage in order to indicate any changes within the stream environment.*

15. The three major sport fish—the westslope cutthroat trout, the bull trout, and the kokanee salmon—depend upon the lake for adult rearing habitat, the rivers as travel corridors, and the tributaries for spawning and juvenile rearing habitat. *The Steering Committee finds that the entire aquatic system needs to be maintained and protected in order to insure the continuance of this important sport fishery.*

16. Bull trout spawn in discrete limited areas throughout the basin. *The Steering Committee recommends that spawning sites be monitored to insure that land use and development activities, as well as fishermen harvests are not adversely affecting bull trout populations.*

17. Howell Creek adjacent to the proposed Cabin Creek coal mine is responsible for ten percent of the known bull trout spawning throughout the entire Flathead River Basin above Flathead Lake. Mine waste dumps are in close proximity to this spawning area. *The Steering Committee finds that the proposed mine poses an unacceptable threat to the quality of the bull trout sport fishery of the basin.*

18. Cutthroat trout are found throughout the entire drainage. Land use and development activities within tributary drainages have the potential to adversely affect cutthroat trout populations. *The Steering Committee recommends that monitoring of cutthroat populations be conducted annually within certain benchmark streams as well as in areas subject to land disturbance in order to identify population trends.*

19. Kokanee salmon are the most abundant gamefish in the basin. The operation of Hungry Horse Dam has affected spawning in the Flathead River. *The Steering Committee recommends that the Bonneville Power Administration continue research to identify suitable flows and to undertake appropriate mitigation.*

20. The shoreline of Flathead Lake previously served as an important spawning area for kokanee salmon. There has been a substantial reduction of spawning success along the lake's shoreline. *The Steering Committee recommends that investigations into the effects that the operation of Kerr and Hungry Horse Dam, as well as water quality impacts from lake and lakeshore development, are having upon kokanee spawning continue.*

21. There is a potential for upstream land use and development activities to affect the quality of Flathead Lake. The condition of the lake can affect fish and zooplankton populations, a major fish food in the lake. *The Steering Committee recommends that a long-term zooplankton monitoring program in the lake be undertaken.*

22. The Flathead Basin's population is expected to grow. Recreation pressures are expected to increase. *The Steering Committee recommends that angler use and harvest rates be monitored in order to provide for sound management of the fishery resource.*

23. Micro-hydro projects either singly or in conjunction with other land uses within a drainage have the potential to cause cumulative adverse impacts to the aquatic environments of the basin. *The Steering Committee recommends that investigations to quantify these impacts continue in order to identify management needs.*

24. The health of the aquatic environment is dependent upon the management of the terrestrial resources of the basin. Detailed aquatic habitat surveys have been completed and a geo-based data system is being developed which relies upon landsat satellite data. *The Steering Committee recommends that these two data bases be integrated and that agencies responsible for maintaining these information systems be encouraged to keep these data base current.*

25. Riparian and floodplain areas are important to maintain wildlife communities. These areas are both publicly and privately owned. They are subject to a wide range of development pressures. *The Steering Committee recommends that long-term monitoring programs be established for these areas.*

26. The wildlife of the Flathead River Basin are important to maintaining the existing quality of life. These wildlife resources utilize a wide range of private and public lands. Although study priorities did not allow intensive investigations, the steering committee recognizes the importance of these wildlife resources. *The Steering Committee recommends that the various agencies responsible for managing the wildlife resources of the basin undertake research to gain a better understanding of the regional nature of this resource.*

PROLOGUE

The November sun crests over the peaks of the Mission Range, the pattern of light and half-light partitioning the calm waters of Flathead Lake. Still in the mountains' shadow, the east side of the lake is an impenetrable steel gray; to the west, daybreak illuminates a mosaic of emerald, turquoise, and deep sapphire, the array of transluscent colors revealing the varied depths of Big Arm Bay.

A small motorboat plies the narrow channel separating the Bay's south shore from Wild Horse Island. The subdued wake and steady course indicate a singleness of purpose. On board, the attention of the two silent passengers is riveted to the trolling rigs affixed to the boat's stern.

Coursing fifty feet below, a bull trout detects a metallic flash, perhaps a shaft of sunlight reflecting off the silver scales of a darting baitfish. The reflex strike of the trout is met by an equal reaction from above, and lure, line, rod and reel become animated links, joining fish and man. Minutes later, one of the anglers leans over the gunwale, dips a large net into the lake, and lifts out the glistening, olive-gold bull trout.

Steering Committee Field Trip, June 1978

For the bull trout, this sequence composes the last act of a life begun seven years earlier in Howell Creek, a tributary of the North Fork of the Flathead River. There, 90 miles north of Big Arm Bay, an egg hatched from amdist a submerged bed of smooth gravel. After three years of development, the trout journeyed downstream to Flathead Lake, where a dependable food supply allowed it to increase its weight 50-fold. This bull trout completed its own spawning runs to Howell Creek in later summers; now its offspring remain to perpetuate the species' ten thousand year lineage in the Flathead drainage.

For the fishermen, landing the 12-pound, 30-inch-long trout highlights a day filled with fresh air, great scenery, and the promise of some fine meals. The experience also reinforces some unspoken bonds, connecting them to the land and the water. For these anglers, the unexcelled recreational opportunities add a satisfying dimension to life in the Flathead Basin.

To the store owner who sold the fishermen gasoline and groceries, the bull trout serves as one of the Flathead's many drawing cards. This businessman and his neighbors have seen tourism grow rapidly during the past decade, and they are enjoying the economic benefits. The clear, clean waters of the Flathead drainage and the productive fishery guarantee a continued inflow of dollars to help fuel the local economy.

Scientific researchers investigating the Flathead Lake ecosystem see the bull trout from different perspectives. The fisheries biologist, who weighs and measures the fish at the dock, gains additional data on movement patterns and growth rates. Coupled with studies on spawning sites, food habits, and population levels, such information helps piece together the puzzling life cycle of *Salvelinus confluentis*.

The limnologist, expert in the chemistry and biology of fresh waters, views the fish as the product of a complex series of events occurring in the Flathead Lake and River system. He recognizes that dissolved oxygen, nutrients, microscopic plants and animals, aquatic insects, and a myriad of other factors all play important roles in the bull trout's environment. Above all, he realizes that the tenuous balance of these elements must be maintained if bull trout are to survive in the Flathead ecosystem.

Finally, to the land manager the bull trout embodies the challenge of how to develop the region's natural resources without sacrificing existing values. In tracing the bull trout's watery migration, the bureaucrat's pencil crosses an international border, various federal, state, and private lands, two county lines, and the boundary of the Flathead Indian Reservation. A map overlay indicates proposed coal mines, oil and gas leases, timber sales, recreational subdivisions, and urban expansion in may areas of the watershed. Given these accelerating development pressures and the tangled jurisdictional network, the land manager understands that many agencies will have to act in concert if bull trout runs are to continue in the Flathead drainage.

As the saga of the trophy bull trout illustrates, man and environment are strongly linked in the Flathead. The high quality of life results from efforts to enjoy and profit from the Basin's natural resources; the continuation of that quality of life depends on the ability to understand and manage this complex ecosystem.

Governor Schwinden signing bill creating the Flathead Basin Commission, April 11, 1983, University of Montana Biological Station on Yellow Bay, Flathead Lake. photo by James Conner

CHAPTER I

FLATHEAD RIVER BASIN ENVIRONMENTAL IMPACT STUDY

University of Montana Archives, M. J. Elrod Collection, The Narrows, Flathead Lake

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Background

In the early 1900s, homesteaders and loggers began the first systematic utilization of the land and resources of the Flathead Basin. Supplies of water, soil, timber, fish, and wildife appeared limitless and, away from the scattered towns, the impact of these settlers on the natural ecosystem was hardly discernible. Despite a steadily growing population, this situation changed little over the next four decades.

Following World War II, a nationwide construction boom brought increased timber harvest and more people to the Flathead. As new clearcuts pocked the high country and housing and industrial developments sprawled across river valleys, residents saw that forests, cropland, clean air and water, and even recreational space were potentially exhaustible resources.

During the next several decades of rapid growth, man's ability to alter the Basin environment outweighed his understanding of its complex ecological processes. This imbalance occasionally had disastrous results. For example, only after Hungry Horse Dam was completed did biologists learn that the dam had eliminated nearly 40% of the cutthroat and bull trout spawning runs from Flathead Lake.

Glacier National Park Collection

More often, development impacts were subtle, such as the small but additive effects of housing developments on water quality. Although the damage from each new septic system or sewer pipe was impossible to measure, the incremental impact of all such nutrient-rich discharges threatened a gradual deterioration of Flathead Lake. Similarly, soil erosion from roads and clearcuts in sensitive areas causes a steady buildup of sediment in tributary streams. The siltation of trout spawning grounds, the reduction of fish populations, and the loss of angling recreation and related revenues were some of the hidden, but inevitable consequences of careless logging operations.

Resource managers through the 1960s, however, gave little consideration to such long-term impacts, nor did they assess the cumulative effects of the many developments proceeding concurrently in the Flathead Basin. Few citizens or government officials recognized the need for intensive environmental studies before authorizing development projects.

In the 1970s, Americans became increasingly concerned with environmental protection. News headlines described a litany of environmental disasters, including oil spills, pesticide contamination, habitat destruction, and unprecedented pollution. These abuses showed that the natural environment, long taken for granted, was actually an ecological web composed of many fragile, interwoven threads. The public began to view air and water quality and fish and wildlife populations as indicators of the human environment. Many citizens called for more sophisticated resource management which recognized these non-commodity values.

At the same time, pressures were mounting for increased natural resource development. Rising demands by consumers, coupled with projected shortages of nonrenewable raw materials, caused mineral and energy prices to rise sharply. The embargo by Middle East oil producers in 1973 heightened concern that the United States attain energy self-sufficiency and spurred exploration for domestic fuel reserves.

Nationally, these two opposing demands—one for environmental accountability and the other for rapid exploitation—combined to dramatically heighten interest in resource management. In the Flathead, this interest focused on Cabin Creek.

Located in British Columbia, Canada, about six miles north of the U.S. border, the Cabin Creek drainage resembles many other tributaries of the North Fork of the Flathead. Its cold, clear waters flow through a narrow, glacier-carved valley, and the timbered slopes and cirque basins provide habitat for grizzly bear, moose, elk, mountain goat, and dozens of other Northern Rocky Mountain wildlife species.

What distinguishes Cabin Creek from neighboring drainages nests in the hearts of two, thousand-foot-high hills near the stream's junction with the North Fork. There, beneath a cloak of lodgepole pine and a mantle of sandstone and shale, lie an estimated 150 million tons of coal.

Although geologists have known about coal in the upper North Fork since 1910, serious attempts to extract reserves from this remote valley are of more recent origin. In the late 1960s, Sage Creek Coal Company Limited obtained British Columbia provincial licenses and began to explore for coal in the Cabin Creek drainage. In 1976, this Canadian corporation submitted a preliminary development plan, which indicated its intention to develop twin, mile-wide, open pit coal mines at the mouth of Cabin Creek.

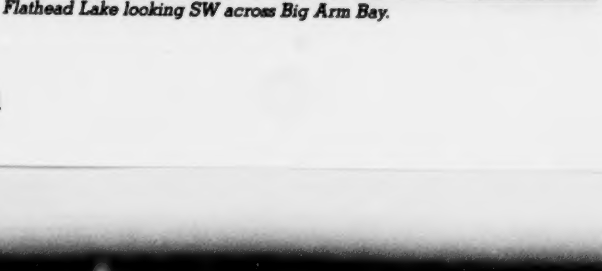
Shock waves from the Cabin Creek proposal reverberated throughout the Flathead Basin. As residents pondered the impacts of the massive mines, they realized that the downstream flow carrying crystal snowmelt from Cabin Creek to the North Fork and Flathead Lake would just as readily carry mine wastes and sediments through the same channels. Few had to be reminded that their exceptional quality of life was based largely on the pristine waters of the Flathead Lake and River systems.

Although at the apex of regional publicity, Cabin Creek's coal-laden North and South Hills merely tipped the iceberg of major resource development proposals in the Flathead Basin during the later 1970s. Public lands under oil and gas lease application rocketed from less than a thousand acres in 1975 to over half a million acres in 1977. An epidemic of mountain pine beetles along the North Fork led American and Canadian foresters to approve expansive clearcuts to harvest bug-killed trees. Subdivisions sprung up on agricultural lands, wildlife habitat, and lake shorelines, while community sewage treatment facilities lagged behind population growth. Dams loomed on the horizon as energy planners continued to eye area rivers for their hydropower potential.

This array of development proposals spurred action to protect the Flathead environment. Area residents organized the Flathead Coalition, a federation of many diverse civic groups, which scrutinized individual projects and raised public awareness of potential impacts. The 1975 Montana Legislature followed suit, directing the state Department of Natural Resources and Conservation to review water resource information from the Flathead Basin and assess the biological and social consequences of coal mines at Cabin Creek. In addition, state and federal bureaucrats grappled with complicated review processes and speculated on the environmental and social impacts of issuing oil and gas leases.

Although these efforts generated some valuable information, they suffered from two major failings. First, each focused on a single proposed action and neglected the cumulative impacts of all development activities in the Flathead Basin. Second, the impact assessments were based on armchair projections, rather than on a rigorous understanding of the biological, social and economic processes in the region.

The call for a broader assessment of resource development in the Flathead originated from the North Fork Interagency Technical Committee, an ad hoc assemblage of local scientists and resource policy makers. Members shared public concerns that an accelerated pace of development might jeopardize the environmental, recreational, and economic base of the region, but they were convinced that information was one key to conserving these values. If we understand how the ecosystem works, they reasoned, then we will be able to manage development so that adverse impacts can be minimized or prevented.



Flathead Lake looking SW across Big Arm Bay.

In 1976, the first formal research proposal was drafted and reviewed. This document, the "Blue Book", as it came to be called, outlined a strategy for determining how all levels of the Flathead Lake-River ecosystem functioned—including water, sediments, nutrients, plankton, aquatic insects, and fish. The authors, Dr. Jack Stanford, a limnologist with the University of Montana Biological Station on Flathead Lake, and Robert Schumacher, a fisheries manager with the state Department of Fish, Wildlife and Parks, received considerable interest from state and federal agencies, but had little initial success in obtaining funds for this massive research undertaking.

Within the year, the outlook brightened. Montana Representative (now Senator) Max Baucus, aware of the state and national significance of the Flathead region and of the escalating resource conflicts, worked with local citizens and the federal Environmental Protection Agency (EPA) to define the scope and funding needs of a basinwide environmental assessment. By June 1977, Baucus had successfully negotiated the congressional appropriations labyrinth, gaining approval for a five-year, $2.9 million "overview environmental impact study".

With federal funds thus earmarked, state officials met to determine initial study objectives and specific research and budget needs. Subsequent discussions with EPA clarified state and federal roles and in January 1978, the Flathead River Basin Environmental Impact Study was formally inaugurated.

Organization and Operation

From its inception, the Flathead River Basin Environmental Impact Study (FRBEIS) was in many ways unique among environmental assessments. First, the study encompassed a large geographic area and many proposed developments, rather than focusing on a limited impact area from a specific project. This regional perspective allowed consideration of the cumulative impacts on the Flathead environment of many seemingly unrelated actions.

Also, the FRBEIS stressed basic research, both to determine existing resource conditions and to elucidate the mechanics of the natural and human environment.

Finally, because the study was initiated in direct response to residents' concerns, EPA established a locally based, volunteer citizen panel to run the study. This FRBEIS Steering Committee, which included members representing industry, conservation groups, resource agencies, and state, local, and tribal governments, assumed responsibility for directing and managing the study. As a major part of this responsibility, the Committee chose the specific studies to be authorized and the level of funding to be provided for them.

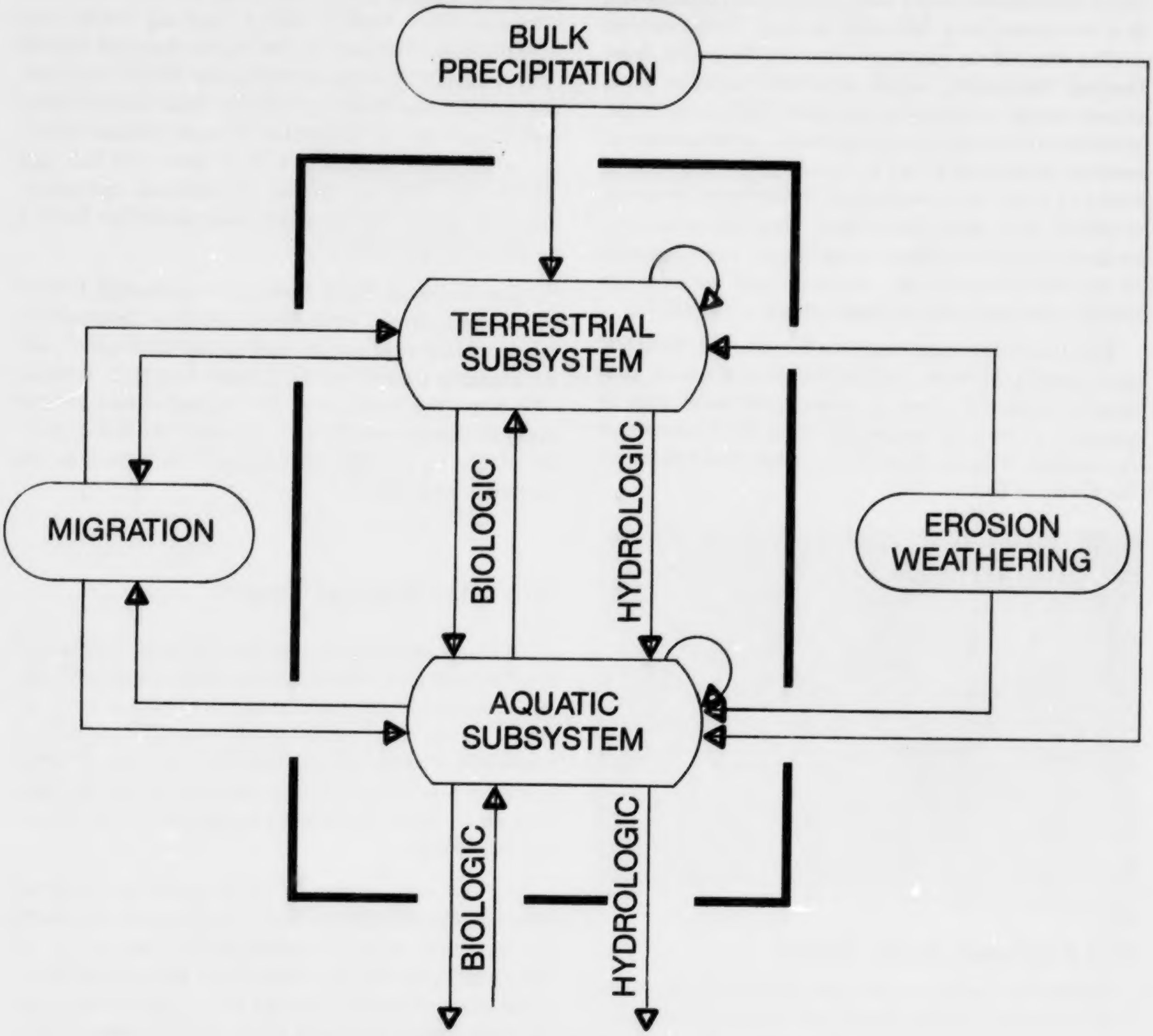
The Steering Committee determined that the overall goal of the study should be "to enhance the existing quality of life in the Flathead River Basin while maintaining and protecting a clean and healthful environment". Members were aware, however, that the group had no vested authority to manage resources or control environmental impacts. They further realized that the FRBEIS was commissioned as a research effort to understand the Flathead environment, not a planning project to direct its development.

Recognizing these limitations, Steering Committee members remained confident that study results could be translated into actions to conserve the Flathead environment. Their strategy was to develop and freely disseminate accurate information on the resources and the functioning of the Flathead ecosystem. Armed with this information, policy makers could determine the environmental consequences of management decisions and citizens could insist that future developments maintain the integrity of the Flathead River Basin.

A program of basic research was thus the cornerstone of the Flathead River Basin Environmental Impact Study. To direct this effort, the Steering Committee formulated a series of study objectives for the basin's water, land, air, and socio-cultural resources (Appendix A). The committee identified the regional economy, airshed, aquatic ecosystem, and riparian wildlife habitat as areas where the lack of information might jeopardize the existing values of the basin environment.

Among these four subject areas, the aquatic ecosystem was considered the most complex and the most susceptible to the impacts of basinwide natural resource development. An intensive research effort, depending on unprecedented coordination between specialists in geology, chemistry, river and lake ecology, and fisheries biology, determined the critical components responsible for the unique natural values of the Flathead watershed. The research also showed how the aquatic system is inextricably linked to land uses and water conditions from headwater tributaries downstream to Flathead Lake (Fig. 1.1).

FIGURE 1.1
Flathead Basin Ecosystem


BULK PRECIPITATION
TERRESTRIAL SUBSYSTEM
MIGRATION
EROSION WEATHERING
BIOLOGIC
HYDROLOGIC
AQUATIC SUBSYSTEM
BIOLOGIC
HYDROLOGIC

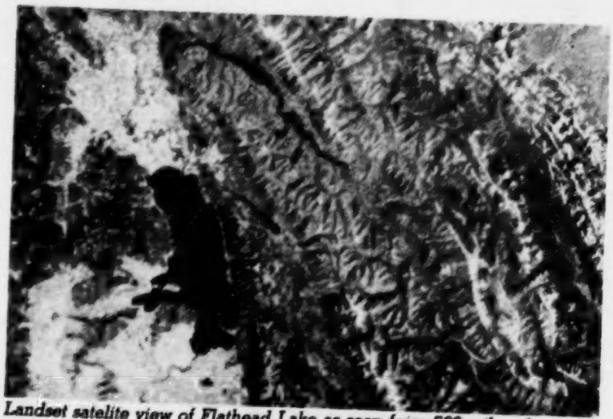
Conceptual Model of the linkages between terrestrial and aquatic subsystems of the Flathead River-Lake Ecosystem.

Source: Stanford modified from Liken and Borman (1978)

Although specific research questions varied among subject areas, studies shared the same general approach. Researchers were directed to determine the existing or "baseline" conditions, to investigate functional processes, and to develop the capability to predict how environmental changes would affect the resource. For example, a biologist studying aquatic insects might first have to determine relative abundance and distribution, then learn the key habitat components and biological processes that support the insects, and finally describe the effects on populations of an increase in stream sediment load.

The Steering Committee set geographic limits for the various research efforts, but did not rely on arbitrary administrative boundaries. Instead, the scope of each study was determined by how that specific resource functioned in the Flathead Basin. Air quality was monitored within a 120-mile long natural basin, which was influenced by uniform weather patterns and thus functioned as a definable airshed. Water-related studies focused on Flathead Lake and its major, free-flowing tributaries, which operated together as a closed system in sediment transport, fish movements, and many other ecological processes. Investigations of nutrient relationships, key to maintaining the quality of Flathead Lake, were conducted throughout the entire drainage area above Kerr Dam. Regional economic patterns and costs of local government were assessed at city and county levels, which formed the effective jurisdictions for financial transactions in the Basin.

This ecosystem approach made research findings from specific locations applicable over a broad geographic area. As a result, researchers were able to generate a comprehensive picture of the dynamics of the airshed, watershed, economy, and other systems of the Flathead Basin.



Landsat satelite view of Flathead Lake as seen from 560 miles above the lake.

The Flathead Basin Today

During the past five years, the Flathead River Basin Environmental Impact Study has achieved a state-of-the-art understanding of the dynamics of the Flathead ecosystem. Current resource conditions are being carefully monitored and study results have allowed many of the impacts of future development to be predicted.

But, despite this advanced level of knowledge, the Flathead Basin remains under seige from within. The threats cover a wide spectrum, from the massive disruptions foreshadowed by proposals like the Cabin Creek Coal mines to the insidious increases in environmental stress caused by haphazard land development. Without coordinated management, these cumulative pressures may irreversibly damage the region's unique resources.

Residents of the Flathead Basin are aware of these threats and have grown staunchly protective of their lifestyle. They realize that a thriving social and economic environment in the region depends largely upon a healthy natural environment. While most residents want reasonable growth for their communities, they do not want to jeopardize the many values—clean air, pure water, productive soils, abundant fish and wildlife populations, diverse recreational opportunities, and spectacular scenery—that make the Basin a desirable place to live.

"The Flathead River Basin Environmental Impact Study has played a vital role in allowing the public to recognize the challenges confronting the region", notes Steering Committee Chairman Thurman Trosper. "We hope the results will be applied wisely to face these challenges and to maintain the remarkable quality of life of all citizens fortunate to reside in the Flathead River Basin."

The FRBEIS Final Report

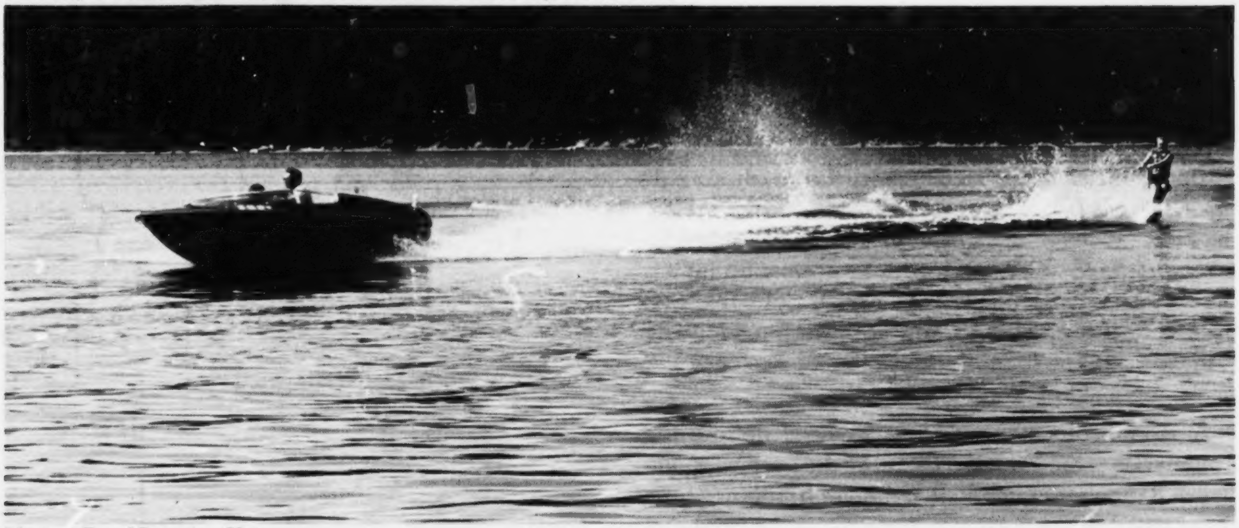
This final report draws together the major findings of the Flathead River Basin Environmental Impact Study into a comprehensive discussion of the basin environment. A description of physical features and cultural resources (Chapter II) is followed by separate chapters detailing how the economic, air, and aquatic systems operate to shape the basin's exceptional natural and human values.

The executive summary which prefaces the report offers recommendations from the Steering Committe on necessary steps to conserve the integrity of the Flathead Basin environment. These recommendations emphasize the need to monitor the critcal environmental components identified by the FRBEIS researchers. An intensive monitoring program would provide an important margin of safety so that any adverse impacts of resource development can be recognized and remedied before serious environmental damage occurs.

This final report is written in a nontechnical style to serve the broad spectrum of persons interested in the Flathead Basin. Readers requiring more detail on results or analytical methods should direct their attention to the appropriate sources, as listed in the bibliography of more than one hundred original research documents produced during the course of the Flathead River Basin Environmental Impact Study (Appendix C).

CHAPTER II
FLATHEAD BASIN ENVIRONMENT

University of Montana Archives, M. J. Elrod Collection, Yellow Bay, Flathead Lake



Montana Travel Promotion Unit

> "Flathead County is a beautiful, resourceful, delightful region. Here in the midst of mountain peaks which rear their exalted crests into the blue of the skies above and greet the eye at every point of the compass, lay fertile lands of the choicest description upon which nature bestows a bounteous rainfall every season. The air is pure. The crops are diversified and abundant. The seasons are temperate and mild. Flourishing trading centers can easily be reached, while the glories and attractions of the mountain wild are within an easy day's journey to all. Here is occupation and here is recreation. What more could the mind of man desire?"
>
> H. L. Wilhelm, *The Coast Magazine*, Jan. 1906.

During the 77 years since publisher H. L. Wilhelm penned his ebullient tribute, droves of settlers and visitors have come to the Flathead Basin in pursuit of both occupation and recreation. Economic opportunities associated with agricultural land, water, timber, and scenery have provided the basis for cultural development; now, over 72,000 residents, joined annually by several million tourists, take advantage of the region's natural resources.

Natural resource development within the Flathead Basin has occurred in a manner largely compatible with environmental integrity. The basin's high country forests and alpine ridges compose one of the largest remaining expanses of undeveloped land in the United States. The Flathead River system offers hundreds of miles of pristine waterways, while Flathead Lake is a scenic and recreational mecca. A diversity of fish and wildlife complements the land and water resources, and contributes to both the natural and cultural values of the Flathead Basin environment.

Physical Features

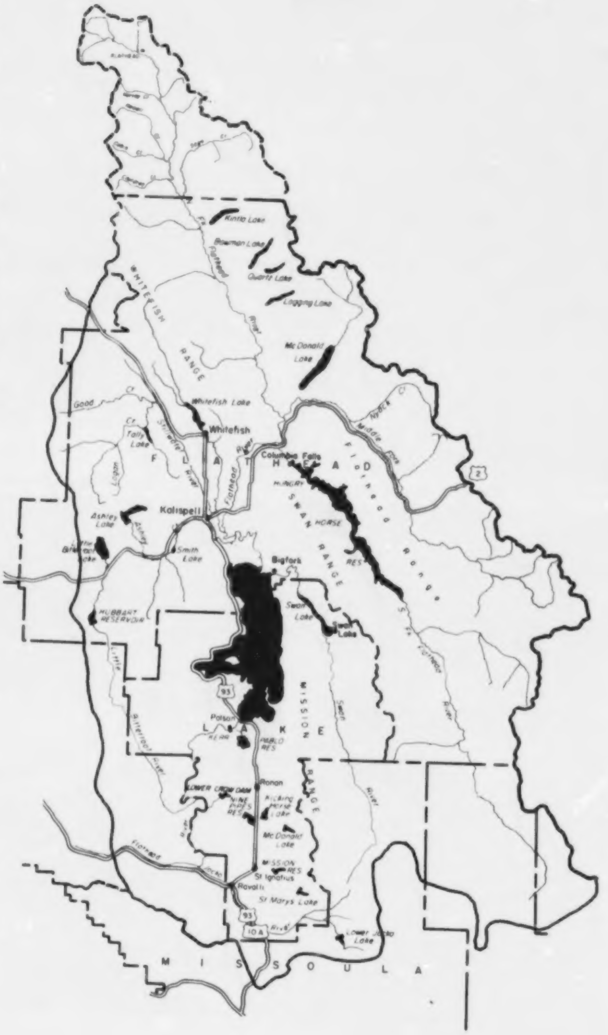
Land Base

The Flathead Basin encompasses the nearly six million acres of land and water within the drainage area of the Flathead River. In map outline, the basin resembles a rough-edged arrowhead, with its narrow tip jutting into the southeastern corner of British Columbia and its broad base spreading across northwestern Montana (Figure 2.1). The long, north-south axis stretches 175 miles; the maximum width is 88 miles.

A mosaic of neighboring watersheds defines the boundaries of the Flathead Basin. To the northwest, the Salish Range separates Flathead River tributaries from those entering the Kootenai River. Over the northeast crest, the rugged peaks and glaciers of the Hudson Bay Divide send waters on a thousand-mile seaward journey via the Saskatchewan River. The eastern border of the Flathead drainage is the Continental Divide, which separates Atlantic-bound Missouri River headwaters from the Pacific-bound Flathead. To the south and west, scattered mountain ranges keep the lower Flathead River from the Clark Fork drainage until the rivers merge at the basin's southwest corner and head west toward the Columbia River and the Pacific Ocean.

FIGURE 2.1

Flathead River Basin



Kintla Lake
Bowman Lake
Quartz Lake
Logging Lake
McDonald Lake
Flathead River
WHITEFISH RANGE
Whitefish Lake
Whitefish
Good Cr
Tally Lake
Stillwater River
Logan
Columbia Falls
Nyack Cr
Middle Fork
FLATHEAD
HUNGRY HORSE RES
SWAN RANGE
Flathead Range
2
Kalispell
Ashley Lake
Ashley
Little Bitterroot Lake
Smith Lake
Bigfork
HUBBART RESERVOIR
Swan Lake
S Fk Flathead River
Little Bitterroot River
93
Polson
KERR
PABLO RES
LAKE
MISSION RANGE
Swan River
Ronan
LOWER CROW DAM
NINE PIPES RES
Kicking Horse Lake
McDonald Lake
MISSION RES
St Ignatius
Ravalli
St Marys Lake
Flathead
Jocko River
10 A
Lower Jocko Lake
MISSOULA

Topographically, the Flathead drainage is split lengthwise (Fig. 2.2). On the east half, the Whitefish, Livingstone, Mission, Swan, and Flathead ranges corrugate the high country forests with mountain ridges running northwest to southeast and reaching elevations of 8,000-10,000 feet. The deep, parallel trenches between mountain ranges contain the Swan River and the North, Middle, and South forks of the Flathead River. These waters drain the heavy mountain snowpack and together provide about 90% of the water flowing through the Flathead watershed.

The west half of the Flathead Basin consists of a 100-mile-long oval depression, interspersed with sets of rolling hills. The broad upper Flathead River Valley dominates the north end, Flathead Lake fills the center, and five distinct valleys—the Mission, Jocko, Little Bitterroot, Camas Prairie, and lower Flathead—compose the southern basin.

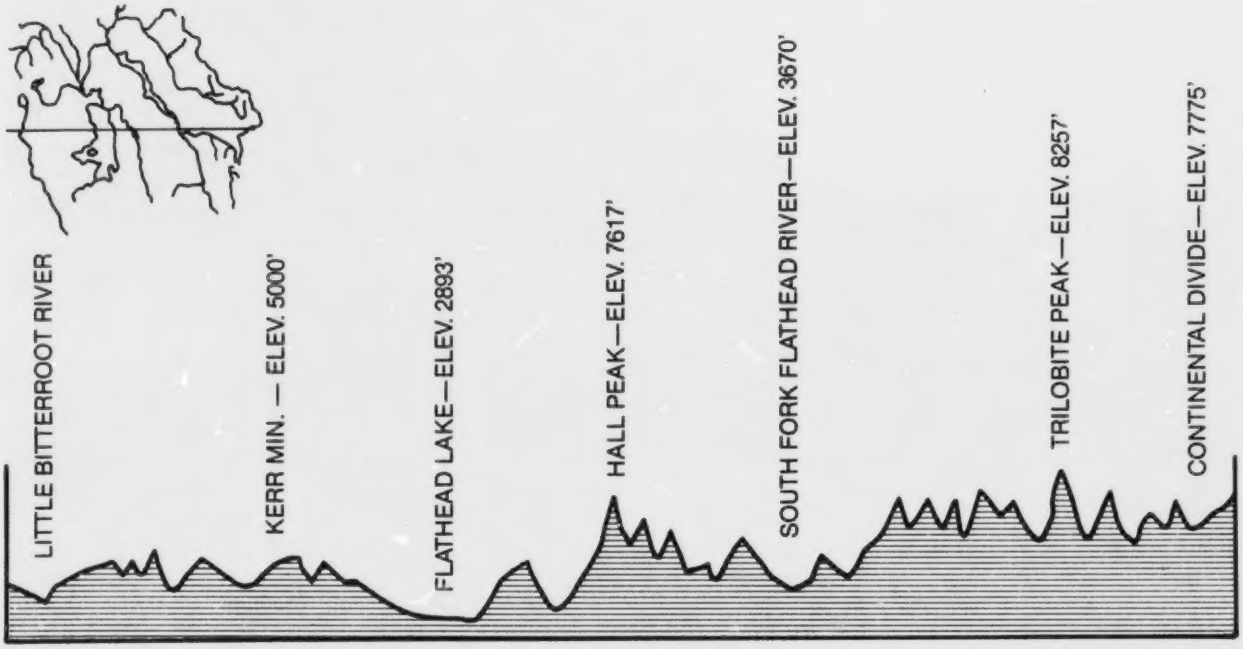
Water flow follows the gentle, south-sloping gradient of the basin floor. The upper Flathead River begins at an elevation of 3,100 feet where the three forks merge near Columbia Falls. The Whitefish and Stillwater rivers, which drain the northwest part of the basin, join the upper Flathead below Kalispell. Near Holt, the Flathead River empties into Flathead Lake; at Bigfork, two miles to the east, lies the mouth of the Swan River, the only other major Flathead Lake tributary. The lower Flathead River flows from the southwest corner of Flathead Lake and drains the arid valley of the southern basin during its 75-mile course. The lower Flathead empties into the Clark Fork River at Paradise at an elevation of 2,500 feet and provides the only outflow channel for the Flathead Basin.

Geology

During its earliest traceable history, approximately one billion years ago, the Flathead region was a flat, low-lying plain periodically flooded by shallow seas. Sediments eroded from distant landmasses to the east settled to the sea floor and eventually solidified into layer upon layer of limestone, sandstone, and mudstone. Over a span of 200-300 thousand years, several tens of thousands of feet of sedimentary rock were formed.

About 150 million years ago, the modern Rocky Mountains began to rise, an aspect of the same geolo-

FIGURE 2.2


LITTLE BITTERROOT RIVER
KERR MTN. — ELEV. 5000'
FLATHEAD LAKE—ELEV. 2893'
HALL PEAK—ELEV. 7617'
SOUTH FORK FLATHEAD RIVER—ELEV. 3670'
TRILOBITE PEAK—ELEV. 8257'
CONTINENTAL DIVIDE—ELEV. 7775'

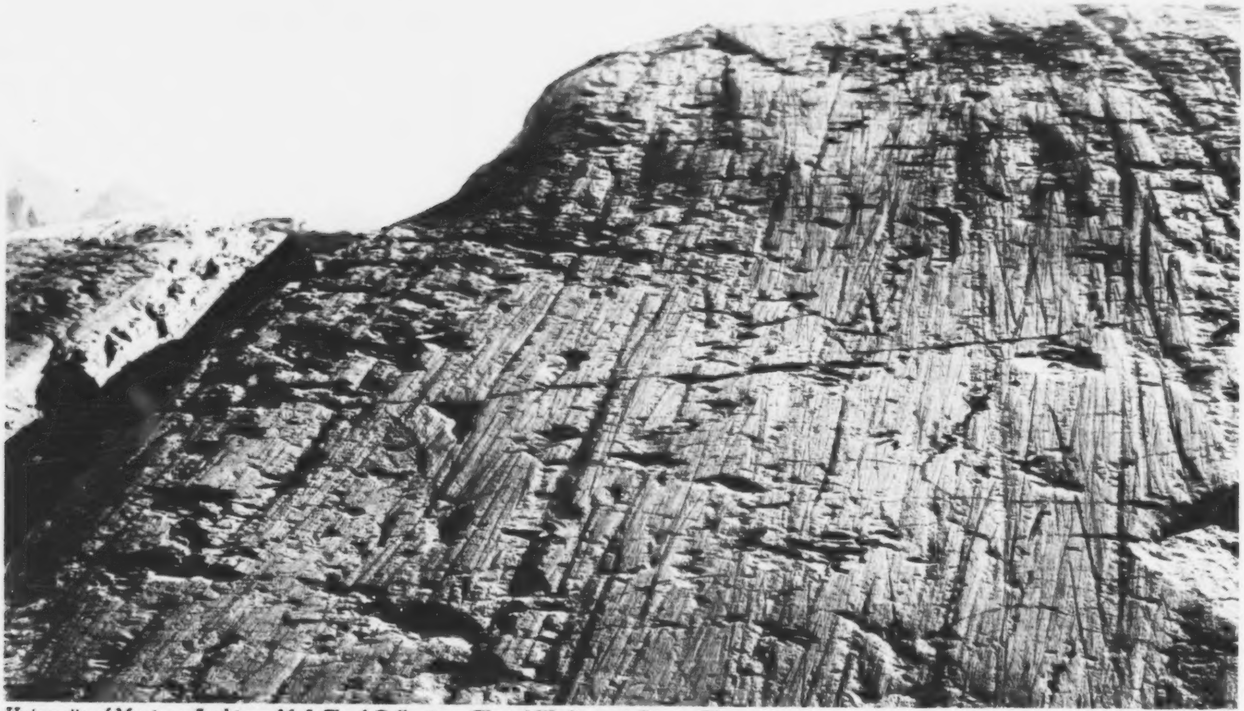
TOPOGRAPHIC CROSS-SECTION FLATHEAD RIVER BASIN gic plate movement that ultimately formed the Atlantic Ocean. The westward drift of the North American continent caused the upward movement of hot, semi-solid rock beneath the earth's 25-mile-thick crust, resulting in uplifting, folding, and buckling of the overlying land surface.

Gradually, long parallel blocks of the sedimentary bedrock were raised to form the mountain ranges now ringing the Flathead Basin. As revealed today in Glacier National Park, these complex mountain-building forces shoved a huge slab of ancient limestones and mudstones from the west towards the east along the Lewis Overthrust Fault. This faulting placed older rocks atop younger, an unusual geologic situation. The Rocky Mountain Trench, an intermountain valley extending 800 miles from the Mission Valley to central British Columbia, formed between the mountain ranges by the downdropping of a block of the uplifted crust.

About 40 million years ago, a prolonged dry period began in the Rocky Mountain region. The low river flows were inadequate to carry sediment from the intermountain basins, and the materials eroded from the mountains gradually built up on valley floors. Half-mile-thick beds of sand and gravel, along with minor coal and oil shale deposits, collected in the Mission, Whitefish, Swan, and upper Flathead valleys. These beds are called the Tertiary deposits for the geologic time period during which they were deposited.

A gradual change to a wetter, cooler climate about three million years ago marked the beginning of the ice ages in the northern Rocky Mountain region. Four times, massive glaciers advanced southward from Canada as heavy snowfalls accumulated much faster than they could be melted. During the most extensive glaciation in the Flathead Basin, the glaciers advanced southward to the site of St. Ignatius. When glaciers retreated between ice ages, major river systems drained the intermountain valleys and carried away much of the accumulated glacial deposits and the older Tertiary deposits.

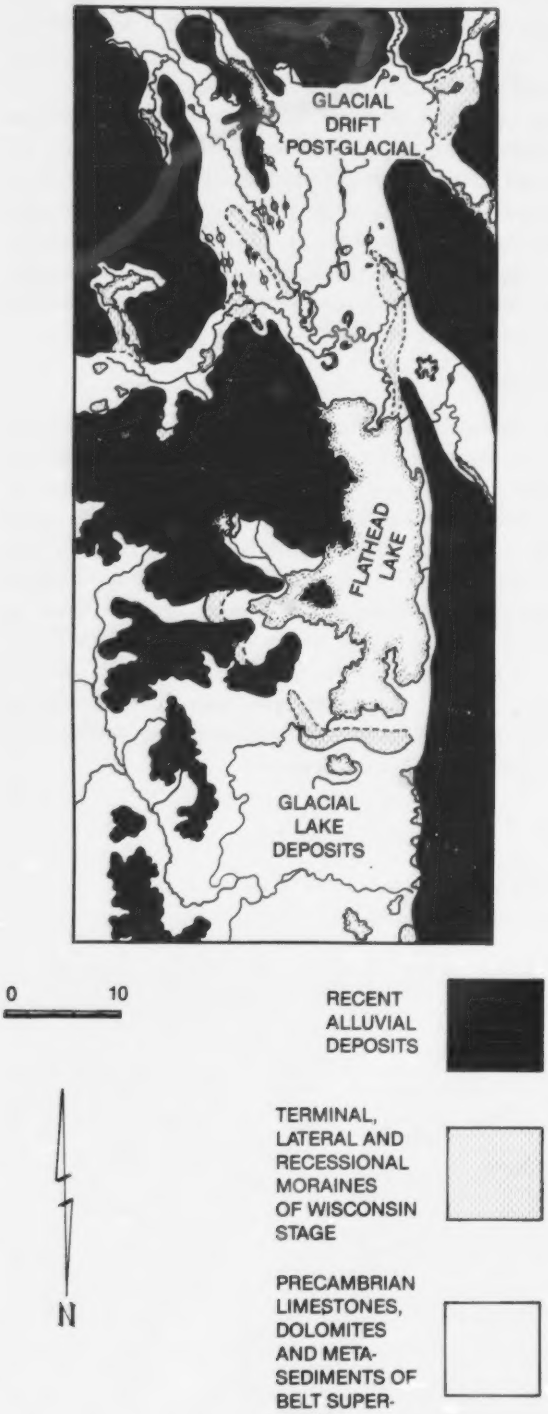
During the last of the ice advances, a continuous ice sheet covered the Rocky Mountain Trench to the site of Flathead Lake. South of this area, Glacial Lake Missoula filled western Montana valleys. The lake, which reached a maximum depth of 2000 feet several times during the glacial period, was created by a huge ice dam near the present Lake Pend Oreille in northern Idaho. About 12,000 years ago, the ice dam gave way and in a few days the entire lake drained. In the southern Flathead Basin, this torrential flow (estimated at 10 cubic miles of water per hour) scoured canyon walls, deposited mounds of debris, and left 20-foot-high ripple marks on the floor of Camas Prairie.



University of Montana Archives, M. J. Elrod Collection, Glacial Workings at Sperry Glacier

FIGURE 2.3

FLATHEAD LAKE AND SURROUNDING AREA GEOLOGY


GLACIAL
DRIFT
POST-GLACIAL
FLATHEAD
LAKE
GLACIAL
LAKE
DEPOSITS
0
10
N
RECENT ALLUVIAL DEPOSITS
TERMINAL, LATERAL AND RECESSIONAL MORAINES OF WISCONSIN STAGE
PRECAMBRIAN LIMESTONES, DOLOMITES AND META-SEDIMENTS OF BELT SUPER-GROUP

The last ice retreat from the valley took place about 10,000 years ago, and only about 50 small glaciers remain today, high in Glacier National Park and the Mission Range. The effects of glacial action, however, still dominate the landscape (Fig. 2.3). Flathead Lake occupies a basin scooped out by moving glaciers, and the numerous pothole, or kettle, lakes in the Mission and upper Flathead valleys were created by melting ice blocks. The large hill south of Polson is a terminal moraine composed of rocks and soil deposited by the melting of the southernmost glacier following the last ice age. The erosional effects of glaciers are displayed in the jagged peaks, knife-sharp ridges, and cirque basins in the higher mountain areas east of the Flathead and Mission valleys, while the lower mountains west of the valley and in the northern end of the Mission Range show rounded form due to complete covering by ice.

Soils

The interaction of geology, climate, and vegetation has defined a coherent pattern of soil types within the Flathead Basin. Glacial erosion and redeposition of the sedimentary bedrock provided the major early influence on soil formation. Since the ice ages, precipitation has weathered exposed bedrock and runoff has served as the major method of soil transport. The accumulation of vegetative litter over thousands of years has completed the process of soil development, adding important nutrients and organic matter to the upper soil layer.

The most productive agricultural soils are found in bottomlands and adjacent level terraces of the upper Flathead River Valley, the Mission Valley, and several smaller valleys of the lower Flathead River drainage. These soils originated from sandstone, siltstone, mudstone, and limestone materials, which were eroded from the mountains by glaciers and carried downslope by meltwater. During this alluvial transport, the glacial material was naturally sorted. Gravels and coarse particles were deposited along the streams and rivers, while the fine clay and silt particles settled out in downstream lakes. The rich valley soils south of Flathead Lake were largely derived from glacial lake sediments. In the central and eastern part of the upper Flathead River Valley, several feet of slackwater-deposited silts overlie sands and gravels.

Most valley soils range from two to five feet deep. The surface horizon generally consists of a thick, dark brown layer rich in organic residues, which accumulated during the thousands of years that grasslands and forests grew upon the alluvial sediments. Valley soils in the Flathead Basin are well-suited for small grains, potatoes, vegetable crops, and hay. Well-drained, sandy soils on some bench land sites near Creston have a characteristic rolling, dune-like topography, indicating transport by wind. These soils are used for the commercial growing of Christmas trees.

The recently deposited soils within the major river flood plains vary considerably in quality. Along the three forks of the Flathead, high flow gradients have limited sediment deposition in the river corridor, and soils are characteristically shallow and gravelly. Along the slower mainstem Flathead River, deep soils have developed through alluvial deposition and the addition of plant litter.

The rolling hills northwest of Flathead Lake and between the valleys south of the lake are ground moraines, composed of unsorted glacial deposits, called till. The soils derived from glacial till are generally silty with ice-rounded rocks and are more suitable for pasture, rangeland, and forest than for cash-crop agriculture.

Soils within the mountainous regions of the Flathead Basin vary widely in character, depending on topographical influences and mode of origin. A 4- to 8-inch surface layer of volcanic ash bolsters the productivity of most mountain soils. This "ash cap" was deposited about 6,700 years ago when Mt. Mazama erupted at the site of the present-day Crater Lake in southwestern Oregon.

Soils surveys indicate that soils deposited by glaciers or flowing water cover about 40% of the national forest lands in the basin, including the intermountain valleys of the Swan River and the forks of the Flathead. These deep, well-drained, and productive soils receive 30 to 50 inches of precipitation annually and support a dense coniferous forest. About 15% of national forest lands have soils which developed in place through weathering of bedrock. These soils have a brown, ash-rich surface and a gravelly substrate. Breaklands with slopes greater than 60% comprise almost half of the national forest lands in the basin. Soil development in these sites is largely a product of glacial scouring and deposition. Soils are thin and rocky in the glacier-scoured alpine areas, while deeper soils under forest cover have developed where glaciers plastered a layer of till to the valley sidewalls.

Climate

The climate of the Flathead Basin reflects a balance between the maritime influence of the Pacific Coast and the drier air and more extreme temperatures of continental air masses (Table 2.1). In winter, the moist Pacific influence is dominant, and the basin is often shrouded by a solid layer of low-lying, gray clouds. Temperatures consequently remain milder than in nearby Rocky Mountain areas, as evidenced by Kalispell's mean January temperature of 20°F. Occasionally, arctic cold waves spill over the Continental Divide, clearing skies and dropping mid-winter temperatures to -20°F. or colder.

TABLE 2.1

Climatological Averages For Flathead River Basin Weather Stations.

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANNUAL
KALISPELL	19.8 / 1.37	24.5 / 1.0	31.8 / .96	43.7 / 1.04	52.2 / 1.57	58.6 / 2.21	65.7 / 1.04	63.1 / 1.09	54.7 / 1.04	43.9 / 1.24	31.0 / 1.43	25.0 / 1.33	42.8 / 15.42
LONEPINE	22.9 / 1.03	26.2 / .82	34.7 / .70	45.7 / .72	54.2 / 1.12	60.3 / 1.62	68.2 / .61	65.9 / .62	57.3 / .88	46.4 / 1.06	33.0 / 1.2	27.8 / 1.08	45.2 / 11.46
POLSON	25.1 / 1.02	27.7 / .97	35.5 / .89	45.1 / 1.16	53.1 / 1.93	59.7 / 1.93	67.4 / 1.0	65.7 / .94	56.9 / 1.23	46.3 / 1.29	34.6 / 1.17	29.7 / 1.16	45.5 / 15.03
ST. IGNATIUS	25.1 / .84	28.4 / .85	36.2 / .99	46.3 / 1.32	54.3 / 2.21	60.2 / 2.51	67.6 / .98	65.6 / 1.04	57.2 / 1.25	46.9 / 1.2	34.7 / 1.01	29.7 / .90	46.0 / 15.1
WEST GLACIER	21.4 / 3.13	24.3 / 2.42	31.4 / 1.81	41.8 / 1.87	51.1 / 2.36	57.0 / 3.02	64.0 / 1.27	62.0 / 1.33	53.3 / 1.89	43.1 / 2.64	30.9 / 3.06	25.7 / 3.26	42.1 / 28.06

Temperature (°F)

Precipitation (in.)

Source: Climatography of the United States No. 81-4
Decennial Census of U.S. Climate

Spring and early summer continue to show the influence of Pacific moisture. Partly cloudy conditions dominate, punctuated by rain and occasional warm, dry periods. By July, high pressure usually moves in, with daytime highs in the 70's and 80's and peak temperatures up to 100°F. Afternoon thunderstorms in the mountains are common throughout the summer. Fall repeats the unsettled weather pattern of spring, as clear skies alternate with periodic entries of moist Pacific weather fronts.

The varied topography of the Flathead Basin causes extreme local fluctuations in precipitation, with greatest amounts collecting where the mountains force the clouds to rise, cool, and release their moisture. The higher mountains annually receive 80 to 120 inches of water, most of which comes as winter snow. Ridge top snowpacks can reach 20 feet or more.

Precipitation in the valleys is light, averaging from 15 to 20 inches per year. May and June are the rainiest months, and about half of the valley precipitation comes during the growing season. Winter snowfalls seldom exceed six inches at a time in the valley, and frequent winter thaws usually keep total snow cover at less than a foot.

The growing season, defined as the average number of days between the last spring frost and the first autumn frost, is about 120 to 130 days on most of the valley floor. The moderating effect of Flathead Lake extends the growing season to over 140 days along the east shore, thus protecting sensitive fruit tree buds from spring frost and contributing to the success of the many orchards in the area. At higher elevations, the growing season shortens dramatically, averaging only 30 days at Polebridge in the upper North Fork Valley.

Prevailing winds parallel the north-south valley axes, and wind speeds are generally low. During late fall and winter, temperature inversions often cause stagnant air conditions in valley locations.

Vegetation

Varied terrain produces dramatic moisture and temperature gradients, resulting in a diverse array of vegetative communities within the limited geographic area of the Flathead Basin (Fig. 2.4). At the lower elevations, the river flood plains are dominated by black cottonwood, a tree well-adapted to abundant water and gravelly soils. Narrow stands of paper birch trees also occur along some river corridors in the northern part of the basin. Major shrubs in the flood plain understory include willow, alder, snowberry, red-osier dogwood, and rose. Natural wetlands are dominated by cattail stands and sedges.

In the dry southwestern corner of the basin, grasslands carpet the benches and rolling hills immediately above the river flood plains. Bluebunch wheatgrass, rough fescue, and Idaho fescue are the dominant grass species; serviceberry is a common shrub on rocky sites.

Above elevations of about 4,000 feet in dry areas on south-facing slopes and 3,000 feet in wetter sites, moisture levels are adequate to support tree growth. Stands of ponderosa pine compose the lowest forest zone. With increasing elevation and increasing moisture, Douglas-fir joins and gradually replaces pondersoa pine as the dominant species. Englemann spruce lines moist, shaded ravines within this Douglas-fir zone. Aspen groves gradually replace cottonwood trees along high-elevation stream courses, and willow and alder continue to be important riparian shrubs.

In a few isolated wet pockets, mixed stands of western red cedar and western hemlock can be found. These two Pacific Coast species indicate very productive growing conditions and signal a diverse tree community, which often includes large western white pine, grand fir, western larch, and spruce.

Above about 5,000 feet, subalpine fir and Englemann spruce become the climax tree species. Menziesia, woodrush, beargrass, queenscup beadlily, and huckleberry are important plant species in the forest understory. At the upper end of the spruce-fir association, climatic conditions become increasingly harsh. Whitebark pine and subalpine fir survive the cold temperatures and short growing season; however, both species exhibit extremely stunted form near timber line at about 8,000 feet. Vegetation in the cirque basins and along the wind-swept mountain ridges above timberline consists of grasses, annual flowering plants, and a few dwarf shrubs.

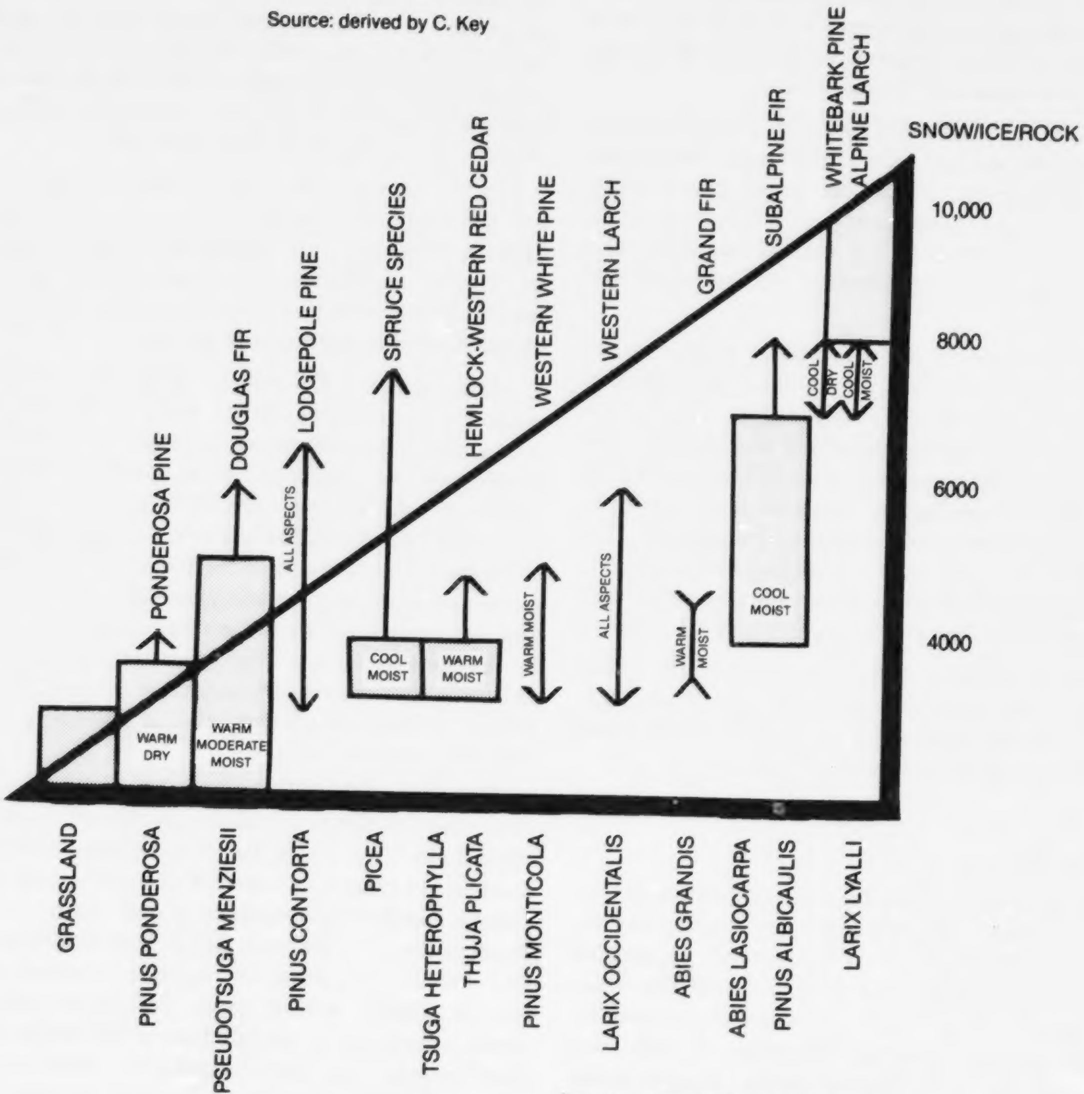
Wild fires profoundly influence tree distribution by removing the climax overstory species and permitting other trees to colonize the burned areas. Extensive areas of the spruce-fir zone are now dominated by exclusive stands of lodgepole pine, the legacy of major forest fires during the early 1900s. Both lodgepole pine and western larch occur on burned-over sites throughout Douglas-fir habitat types. Lodgepole pine and western larch are considered early successional species because they cannot reproduce under a closed canopy. In the absence of fire, logging, or other disturbance, climax species, such as spruce, fir, and Douglas-fir, will eventually replace the colonizers.

Permanent settlement has caused a number of changes in Flathead Basin vegetation. Mature spruce and larch, once common along the Flathead River upstream from Kalispell, were removed during early logging and land-clearing operations. Many of the large white pines from the lower elevation forested slopes on the east side of the Basin were intensively harvested, and blister rust disease, accidentally introduced from Europe during the 1920s, decimated remaining stands. Grasslands grading into open ponderosa pine savannahs once dominated the bench land east of the upper Flathead River and major portions of the Mission Valley. Most of the large pines were cleared and the grasslands plowed, leaving today's grainfields, pastures, and scattered dense stands of young pines.

FIGURE 2.4

Generalized Vegetation — Flathead River Basin

Source: derived by C. Key


PONDEROSA PINE
DOUGLAS FIR
LODGEPOLE PINE
SPRUCE SPECIES
HEMLOCK-WESTERN RED CEDAR
WESTERN WHITE PINE
WESTERN LARCH
GRAND FIR
SUBALPINE FIR
WHITEBARK PINE
ALPINE LARCH
SNOW/ICE/ROCK
10,000
8000
6000
4000
WARM DRY
WARM MODERATE MOIST
ALL ASPECTS
COOL MOIST
WARM MOIST
WARM MOIST
ALL ASPECTS
WARM MOIST
COOL MOIST
COOL DRY
COOL MOIST
GRASSLAND
PINUS PONDEROSA
PSEUDOTSUGA MENZIESII
PINUS CONTORTA
PICEA
TSUGA HETEROPHYLLA
THUJA PLICATA
PINUS MONTICOLA
LARIX OCCIDENTALIS
ABIES GRANDIS
ABIES LASIOCARPA
PINUS ALBICAULIS
LARIX LYALLI

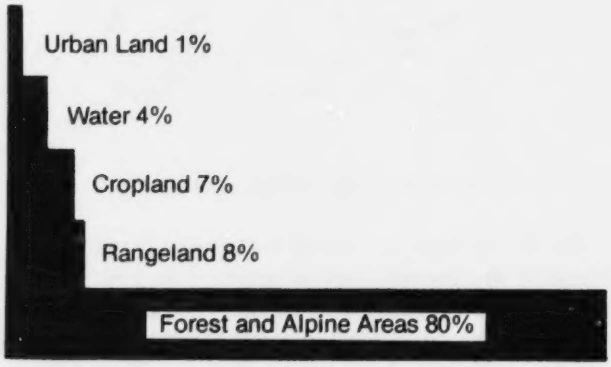
Arrows represent species range
Blocks represent habitat type
Series after Pfister, et. al. (1977)

Fire suppression, a keystone of forest management for most of this century, has altered natural vegetation cycles within the Flathead Basin. Historically, small lightning-caused fires swept through forested areas about every 20 years, reducing the accumulation of downed timber and forest litter and opening the forest canopy. Now, dense stands of 80- to 100-year-old lodgepole pines are common. These older trees are particularly susceptible to infestation by mountain pine beetles, which are killing lodgepole on thousands of acres throughout the basin. The buildup of wood fuel on the forest floor allowed by fire suppression has greatly increased the chance of a major forest fire during a particularly dry summer or autumn.

The quality of rangeland vegetation has been greatly altered since early settlers found "stirrup-high" stands of native bunchgrasses carpeting the southwestern portion of the Flathead Basin. Many homesteaders plowed native grasslands only to discover that precipitation was inadequate to support cultivated crops. Excessive stocking rates for livestock on confined homesteads reduced the size, vigor, and densities of the most nutritious grasses, and allowed undesirable native species, such as lupine and arrowleaf balsamroot, to invade the ranges. Overgrazing and soil tillage have also permitted exotic weed species to become established in many areas. Canadian thistle, spotted knapweed, and leafy spurge are the three primary targets of control efforts because of their capacity for rapid colonization and their unpalatability to livestock.

FIGURE 2.5

Flathead River Basin
Generalized Land Use



Land Cover

Topographic and climatic factors confine most settlement to the low-elevation, relatively flat regions of the basin. The upper Flathead River Valley and the Mission Valley have been most extensively developed for agricultural and urban uses; additional important agricultural areas include the Jocko and Little Bitterroot valleys. The treeless slopes in the southwestern corner of the basin provide the most significant rangeland, while forests dominate the mountainous terrain which composes the vast majority of the basin area (Fig. 2.5).

Water Resources

Surface waters. An abundance of clean lakes, rivers, and streams has given the Flathead Basin a national reputation for high-quality water resources. Flathead Lake is the geographic, scenic, and recreational focus of the basin. With a full-pool surface area of 126,000 acres, Flathead Lake encompasses the largest area of any natural freshwater lake in the western United States. Residential dwellings ring much of the 161-mile perimeter, while undeveloped shoreline sections are dominated by coniferous forest, rock outcrops, and gravel beaches. The Mission Mountains provide the scenic backdrop to the east side of the lake, forests dominate the northwest shore, and rolling grasslands back the southwest corner.

Swan and Whitefish lakes are among the largest natural water bodies in the Flathead Basin, and each provides a variety of recreational opportunities. Other popular lakes with noted fisheries include Ashley, Little Biterroot, and Foy west of Kalispell, along with Lake Mary Ronan west of Flathead Lake. Tally Lake is the deepest lake in the Flathead Basin at 492 feet. Echo Lake and Lake Blaine, the largest of the approximately 30 glacial pothole lakes east of the upper Flathead River, are both ringed by residential development and host warm-water fisheries and intensive boating activity. Five of the narrow valleys draining the west side of Glacier National Park contain large, pristine lakes, including scenic, ten-mile long Lake McDonald. Scores of alpine lakes dot Jewel Basin east of Kalispell and the crest of the southern Mission Range.

Legislation passed by Congress in 1976 classified a total of 219 miles of the North, Middle, and South forks of the Flathead River under the provisions of the National Wild and Scenic Rivers Act (Table 2.2). These waters will be maintained in their free-flowing state for recreation, fish and wildlife habitat, and scientific re-

TABLE 2.2

National Wild And Scenic River Flathead River, Montana

		Distance
North Fork Flathead River		
Scenic—	U.S./Canadian boundary to Camas Bridge	40.7 miles
Recreational—	Camas Bridge to confluence with Middle Fork	17.6 miles
Middle Fork Flathead River		
Wild—	Headwaters to Bear Creek	46.6 miles
Recreational—	Bear Creek to confluence with South Fork	54.0 miles
South Fork Flathead River		
Wild—	Headwaters to confluence with Spotted Bear River	51.3 miles
Recreational—	Spotted Bear River to Hungry Horse Reservoir	8.8 miles

search. The main Flathead River is also a valued recreational waterway. Above Flathead Lake, the upper river meanders through a large, cottonwood-lined flood plain; below the lake, the deep, blue-green lower Flathead carves a scenic route through the siltstone cliffs and open rangeland of the Flathead Reservation.

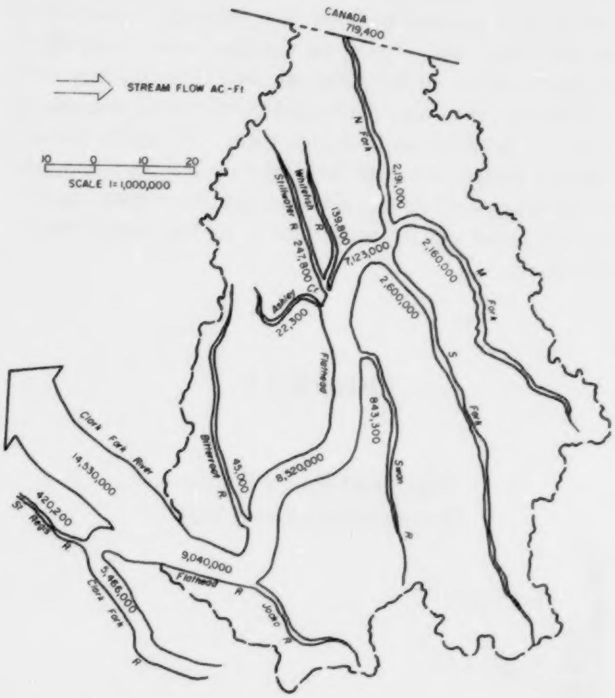
The annual discharge of the Flathead River system averages nine million acre-feet, a volume which, if contained, would raise a 70-foot-high column of water over the entire surface of Flathead Lake (Fig. 2.6). Flow rate for the lower Flathead River averages over 12,000 cubic feet per second (a cubic foot contains 7½ gallons of water). The lower Flathead ranks fourth in volume among Montana rivers, behind the Kootenai, Yellowstone, and Clark Fork. (The Flathead is larger than the Clark Fork when the two rivers merge at Paradise; however, the Clark Fork retains its name and becomes Montana's largest river with the addition of Flathead waters.)

The three forks of the Flathead River together supply about 80% of the water carried within the Flathead system. Flows on the North Fork average about 1,000 cfs at the Canadian border, but a multitude of tributaries swell the volume to 3,000 cfs near Columbia Falls. Middle Fork flows above Columbia Falls also averages about 3,000 cfs. On both forks, peak spring runoff often exceeds 10 times the average flow. During June 1964, an above-normal snowpack rapidly melted by heavy rains brought the North and Middle forks to record high levels and caused an estimated $28 million of property damage in the upper Flathead River Valley. The Middle Fork drainage was particularly hard hit, as over 10 inches of rain in a two-day period brought flows of 140,000 cfs, an event with an expected frequency of once in 200 years. Low flows generally occur in winter when many tributary streams are frozen and in late summer before the fall rains begin. Both the North and Middle forks have recorded flow volumes below 200 cfs.

The Middle Fork, renowned for its whitewater recreation, experiences an average elevational drop of 26 feet per mile, while the North Fork falls 15 feet per mile. In contrast, the meandering main upper Flathead River has a 6-foot-per-mile gradient between Columbia Falls and Kalispell, and only a 1-foot-per-mile drop between Kalispell and Flathead Lake.

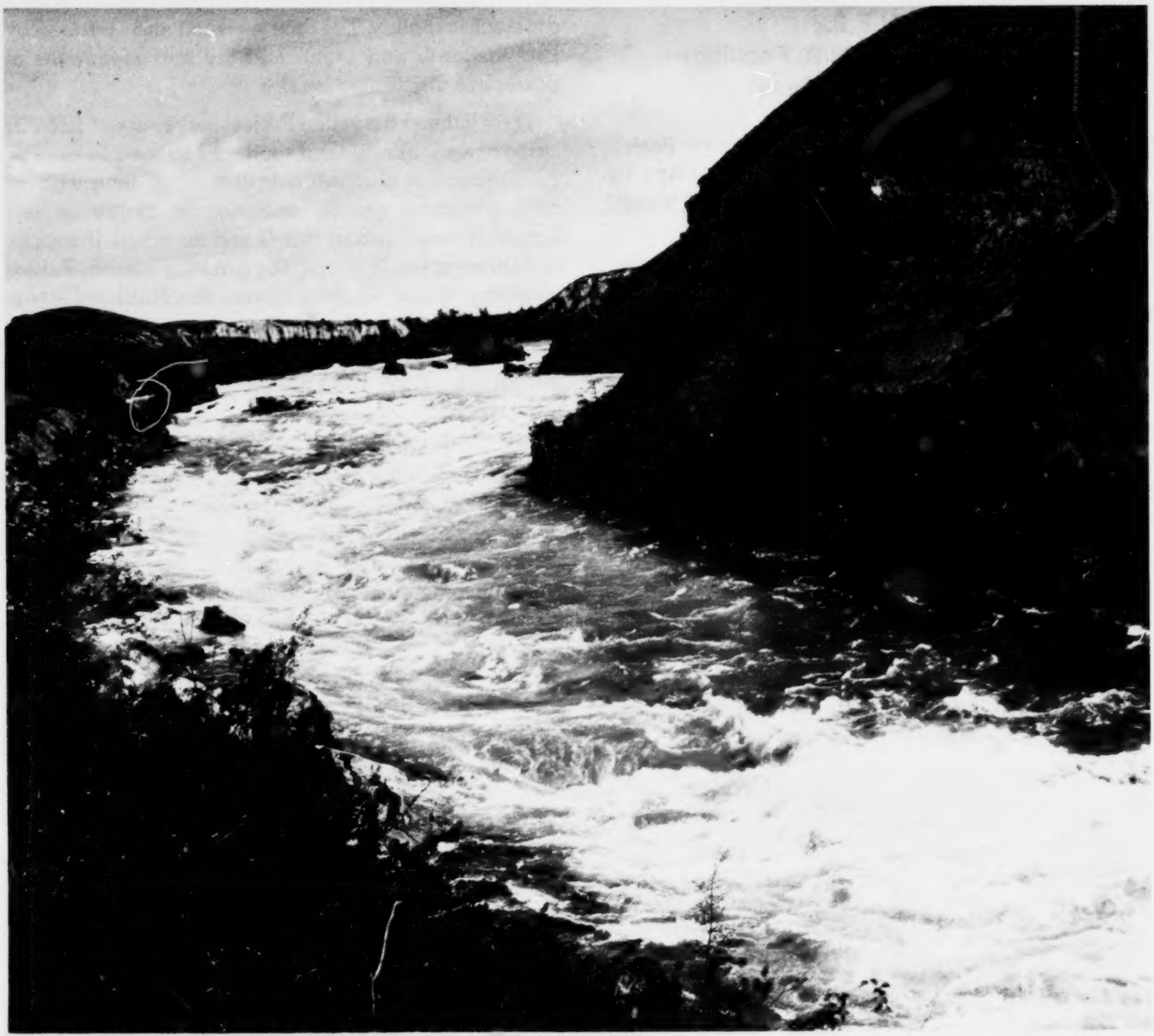
FIGURE 2.6

Annual Discharge Flathead River Basin Water Yield in Acre-Feet



Source: U.S.D.A. Soil Conservation Service-1977

The South Fork flows for 60 miles, mainly in the Bob Marshall Wilderness, before meeting its own waters backed up on Hungry Horse Reservoir. Flow volume in the five-mile section of the South Fork between Hungry Horse Dam and the upper Flathead River varies



University of Montana Archives, M. J. Elrod Collection, Flathead River below Lake

drastically according to the power generation schedule. Hours or days of maximum power generation with flows above 11,000 cfs are often followed by extended periods of no power generation with flows about 150 cfs. As a result, water levels in the South Fork below the dam can fluctuate as much as eight feet per day, and levels in the main Flathead River below the South Fork confluence vary by as much as five feet per day.

The Whitefish and Stillwater rivers merge southeast of Kalispell and contribute a combined 5% of the flow of the upper Flathead. The Swan River, which empties directly into Flathead Lake at Bigfork, provides about one-tenth of the lake inflow. The Jocko River is the largest tributary of the lower Flathead River, although it contributes less than 4% of the total flow volume.

Water development. Large-scale hydroelectric facilities have been developed at three locations in the Flathead Basin (Table 2.3). Hungry Horse Dam on the South Fork of the Flathead River was completed in 1953 as a power and flood control project of the federal Bureau of Reclamation. The 560-foot-high dam, which impounds 35-mile-long Hungry Horse Reservoir, is used to help meet the daily maximum power demands of the Pacific Northwest region. Under its "peaking" schedule, power production varies drastically, reaching 320 megawatts when maximum discharge brings all four generators into operation. Power from Hungry Horse Dam enters the Bonneville Power Administration transmission system, which distributes power from more than 30 federal dams in the Pacific Northwest.

TABLE 2.3
Existing Hydroelectric Facilities Flathead River Basin

Name	Operating Entity	Peak Capacity Kilowatts
Hungry Horse	U.S.D.I. Bureau of Reclamation	320,000
Bigfork	Pacific Power and Light	4,000
Kerr	Montana Power Co.	180,000

The Kerr Dam hydroelectric plant on the lower Flathead River five miles south of Polson began operation in 1938. The dam is operated by the Montana Power Company on land leased from the Confederated Salish and Kootenai Tribes. Kerr Dam generates an average of 125 megawatts of electricity through the course of a normal water year; peak generation capacity is 180 megawatts. Power produced at the dam enters Montana Power's transmission system, except for a block of power set aside for Flathead Irrigation and Power Project.

Bigfork Dam, located on the Swan River less than one mile from Flathead Lake, houses a small hydroelectric facility. The dam is owned and operated by Pacific Power and Light, and the four megawatts of power are distributed locally.

The Flathead Irrigation Project serves about 127,000 acres of agricultural land south of Flathead Lake. The project consists of an intricate network of natural channels, irrigation canals, and storage reservoirs designed to retain spring runoff and distribute the water to cultivated lands during the growing season. Pablo, Ninepipe, Crow, Kicking Horse, and Hubbard reservoirs are among the largest artificial impoundments in the irrigation system; McDonald, Tabor, and Little Bitterroot are natural lakes adapted for controlled irrigation releases.

The federal Bureau of Indian Affairs administers the Flathead Irrigation Project and assesses fees to irrigators based on water use. One division of the BIA project owns and maintains most of the power lines on the reservation and sells electricity to local users. The Flathead Irrigation Project also maintains three large electric pumps on the Flathead River two miles above Kerr Dam. These pumps, which raise water 335 feet into the irrigation canal system, require substantial amounts of electricity and are used only when other water supplies run short.

Montana Travel Promotion Unit, Kerr Dam—Flathead River

Water quality. Excellent quality water characterizes most of the Flathead Lake and River system (Table 2.4). The regional water quality is initially shaped in the high elevation watersheds, where great volumes of essentially pure rainwater and snowmelt are channeled into progressively larger tributary streams. Physical events, including soil erosion and the leaching of minerals from rocks, control water composition throughout this downstream course. The moderate concentrations of dissolved materials, the absence of excessive salts or heavy metals, and the high concentrations of dissolved oxygen are conducive to aquatic life; low nutrient concentrations, however, limit the growth of aquatic plants and thus keep the amount of biological matter consistently low. Concentrations of fecal coliform bacteria, which indicates contamination by human or animal wastes, are well below levels of concern.

TABLE 2.4
Apparent and Potential Man-Caused Water Quality Problems in Streams —Flathead River Basin*

Streams	Suspected Pollutants
Ashley Creek	C,N,P,NH_3
Big Creek	TSS
Canyon Creek	TSS
Coal Creek	TSS
Red Meadow Creek	TSS
Skyland Creek	TSS
S. Fork Flathead River below Hungry Horse Dam	Temperature
Stillwater River below Logan Creek	TSS,N,P
Whale Creek	TSS
Whitefish River below Whitefish Lake	TSS,N,P

*Source: Montana Water Quality, 1982, Montana Department Health and Environmental Sciences

The mountain streams run extremely clear under low flow conditions. During spring runoff, however, tremendous amounts of unconsolidated bank sediments are eroded into the stream channels. These fine sediments make the rivers turbid from mid-May to mid-June in most years.

The adverse impacts of timber practices are evident in some tributary drainages. Extensive logging and road systems have caused soil erosion and sedimentation of stream bottoms, and consequently have reduced local populations of aquatic insects and fish. High sediment yields also increase streamborne nutrient loads and may degrade water quality in downstream lakes.

As tributary streams merge and the waters of the Flathead system enter the populated valleys, human activities have an increasing effect on water quality. In the highly polluted Ashley Creek drainage, livestock operations and residential developments cause a steady downstream increase in concentrations of fecal coliform bacteria, sediments, and nutrients below Ashley Lake. Water quality changes are more dramatic below Kalispell, due in large part to the effluent from the municipal sewage treatment plant. At its confluence with the Flathead River, Ashley Creek is slow-moving and murky, with mats of aquatic vegetation, high bacteria levels, and low dissolved oxygen levels attesting to the degraded water quality.

The Stillwater River retains relatively high water quality throughout its course, although sediments and fecal coliform bacteria increase moderately along a downstream progression. Naturally erosive banks, aggravated by irrigation practices, are the main source of the sediments which cloud the lower Stillwater. The coliform counts result from the presence of livestock in the stream corridor.

Water quality in Whitefish Lake has been the subject of growing local concern in light of the recent boom in shoreline residential development and the resulting possibility of nutrient pollution. A citizen-directed Whitefish Basin Project is currently promoting a research program to determine existing water quality and to identify threats to the integrity of Whitefish Lake.

The Whitefish River below the lake experiences natural and agriculture-related sedimentation from bank sloughing. The Whitefish municipal sewage treatment plant has been identified as a point source of phosphate and nitrate pollution. This pollution is aggravated by excessive irrigation withdrawals and the resultant low instream flows, which impair the ability of the Whitefish River to dilute pollutants.

The effects of tributary flows and urban and agricultural runoff on water quality in the upper Flathead River are largely mitigated by its great volume. When it reaches Flathead Lake, the Flathead River displays slightly elevated sediment concentrations, but generally maintains the very healthy conditions characteristic of its three forks.

Water quality in Flathead Lake is ranked in one of the highest categories under Montana regulations. Many shoreline residences use untreated lake water as their domestic water source, although state officials do recommend chlorination for all surface waters. The domestic water supply for Somers consists of chlorinated lake water pumped from a depth of about 100 feet in Hatchery Bay. Water chemistry in Flathead Lake mirrors its tributaries and is slightly alkaline, well-buffered, and low in nutrients and dissolved solids. Annual spring runoff brings a "plume" of turbid water from the Flathead River into the north end of the lake. The entire lake surface is usually clouded by sediment particles by the end of June and clear again by August when the sediments have settled to the lake bottom.

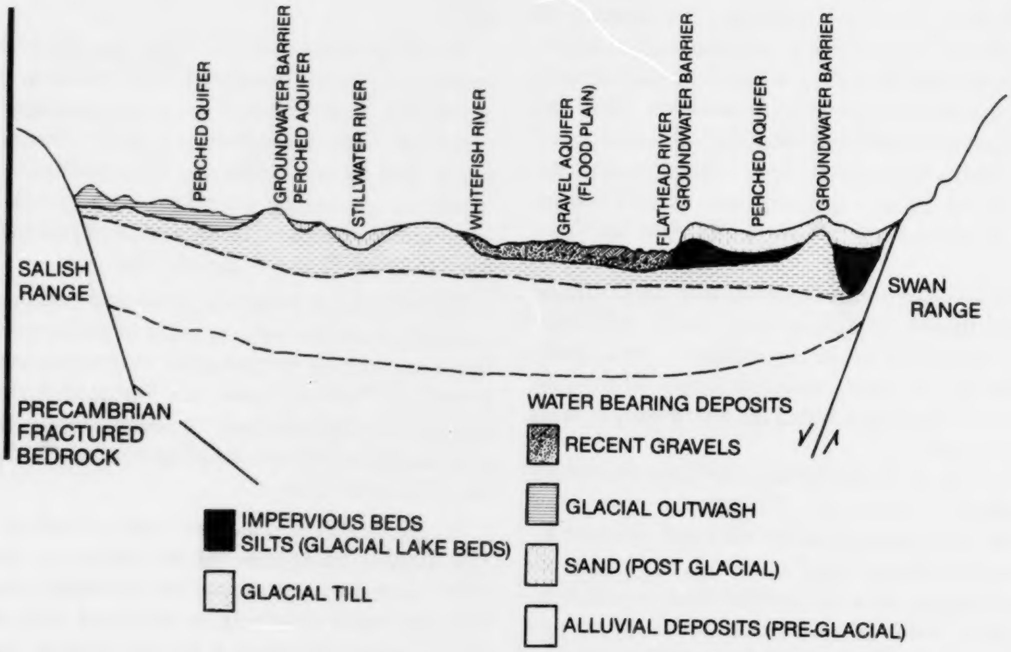
Water quality in most drainages south of Flathead Lake suffers from the influences of intensive agriculture. After clear streams leave the west slope of the Mission Mountains, the Flathead Irrigation Project channels the flow for agricultural uses on the Mission Valley floor. Return flow from flood irrigation, drainage from livestock feedlots, and soil erosion produce extremely high loads of suspended solids, nutrients, and bacteria in the Mission, Post, and Crow Creek drainages. Naturally erosive stream banks, aggravated by chronic overgrazing, give the Little Bitterroot River the highest sediment levels of any stream monitored in the Flathead Basin. Effluent from municipal wastewater lagoons and urban storm runoff constitute additional pollution sources for a number of the tributaries of the lower Flathead River. Although degraded water has eliminated trout from the majority of valley streams south of Flathead Lake, the Jocko River maintains relatively good coldwater habitat through most of its course. Irrigation withdrawals, however, leave parts of the river with little or no flow each summer, and thus prevent the Jocko from reaching its potential as a productive fishery.

The lower Flathead River displays excellent water quality at the outflow of Flathead Lake. As the river cuts southward through the southern basin's ancient glacial lakebed, fine sediments eroded from the steep cliffs give the lower Flathead its characteristic cloudy cast and aquamarine color.

Groundwater. The Flathead Basin is underlain by extensive groundwater resources which supply much of the water used by residences, agriculture, and industry in the region (Fig. 2.7). The single most important underground water-bearing structure is the flood plain aquifer beneath the upper Flathead River Valley.

FIGURE 2.7

**COMPOSITE HYDROLOGIC CROSS-SECTION
FLATHEAD VALLEY — NORTH OF KALISPELL**


PERCHED QUIFER
GROUNDWATER BARRIER
PERCHED AQUIFER
STILLWATER RIVER
WHITEFISH RIVER
GRAVEL AQUIFER (FLOOD PLAIN)
FLATHEAD RIVER
GROUNDWATER BARRIER
PERCHED AQUIFER
GROUNDWATER BARRIER
SALISH RANGE
SWAN RANGE
PRECAMBRIAN FRACTURED BEDROCK
WATER BEARING DEPOSITS
RECENT GRAVELS
GLACIAL OUTWASH
SAND (POST GLACIAL)
ALLUVIAL DEPOSITS (PRE-GLACIAL)
IMPERVIOUS BEDS
SILTS (GLACIAL LAKE BEDS)
GLACIAL TILL

From Columbia Falls to Flathead Lake, this aquifer consists of a 30-foot-deep, 5-mile-wide bed of sand and gravel, which is filled to the seasonal water table. Many wells in the upper Flathead Valley tap this water source; in addition, the aquifer feeds a spring which provides a major water supply for Kalispell. A 1965 study estimated the water storage capacity of the upper Flathead River flood plain aquifer at 55 billion gallons and annual use at about 3.4 billion gallons. Recent population growth has undoubtedly increased groundwater use in the region.

Shallow aquifers also constitute major groundwater reservoirs under the Whitefish and Stillwater flood plains and beneath the large valleys south of Flathead Lake. Precipitation, infiltration from streamflow during spring runoff, and percolation of irrigation water are the major recharge sources for flood plain aquifers.

The second most important underground reservoirs are the deep, pressurized (artesian) aquifers which underlie most valley locations throughout the Flathead Basin. These aquifers are set in unconsolidated sand and gravel beds and capped by thick layers of compacted glacial till and sediments. Wells reaching the artesian aquifers generally range from 200 to 400 feet in depth. Most recharge occurs along the mountain front to the east of the Flathead and Mission valleys, where the aquifers approach the land surface. Precipitation and snowmelt runoff are the principal sources of recharge.

Bedrock aquifers are important groundwater sources in many areas with hilly or mountainous terrain. These aquifers consist of water trapped within the faults and fractures of Precambrian rocks. In most cases, storage volume is relatively small, and water yields are only sufficient for domestic use. Many wells northwest of Flathead Lake tap a fractured limestone aquifer which extends from Rollins northward to Whitefish Lake.

The groundwater in the Flathead Basin is relatively uniform in chemical makeup and of good quality. Regional groundwater has a high calcium content, reflecting the chemical composition of the underlying limestone bedrock and of the glacial deposits derived from bedrock. Although such "hard" water increases soap consumption and promotes mineral deposits on plumbing surfaces, hardness poses no health hazard and may, in fact, supply needed dietary minerals.

In a few recent instances, groundwater systems in the Flathead Basin have proven to be susceptible to pollution from human activities. Nitrate pollution has become a localized problem in some wells northwest of Flathead Lake. High nitrate concentrations are symptomatic of septic effluent and indicate that wastewater is percolating into the groundwater through fractures in the limestone bedrock. Near Somers, one well in the same aquifer was contaminated by the seepage of chemicals from a tannery.

Recent analysis of specialized aerial photographs has indicated high nitrogen discharge into the Flathead River from the shallow flood plain aquifer north of Kalispell. This groundwater flow came from the residential Evergreen area, where concentrated septic systems and the shallow water table increase the likelihood of wastewater discharge into the aquifer. Earlier studies of the same aquifer revealed pollution by industrial glue which had been stored below the water table, a problem which has since been corrected. In general, natural purification by the soil and effective dilution by the tremendous water volume of the flood plain aquifer are thought to keep pollutants well below harmful levels in this critical groundwater source.

Sampling has not revealed contamination of the deep artesian aquifer in the Flathead Basin. Hydrologists caution, however, that potential pollution sources should not be located at the base of the Mission Mountains. This area is the predominant recharge zone for the deep aquifer, and wastewater might percolate through the thin soil mantle and contaminate portions of the aquifer. Similarly, the Foy Lake-Whitefish Lake region has been identified as a sensitive recharge area for the fractured limestone aquifer lying northwest of Flathead Lake.

Geothermal groundwater sources have been discovered in the Camas Prairie and Little Bitterroot valleys. Camas Hot Springs, owned by the Confederated Salish and Kootenai Tribes, offers mineral baths for therapeutic uses and recreation. The nearby Camp Aqua Well taps a hot-water reservoir 244 feet below the surface, with water temperatures of 125°F. The Camp Aqua Well, Montana's first geothermal artesian well in 1913, has been eyed as a potential heat source for industrial development.

Cultural Setting

History

Early Indian history. Stone projectile points from western Montana locations near the Flathead Basin suggest that human habitation in the region dates from about 10,000 years ago (Table 2.8). With neither the tremendous salmon resource of the Pacific Coast nor the abundant bison of the plains, early people in the intermountain region had to use a wide variety of hunting, fishing, and plant preparation techniques for subsistence. Root-roasting pits, where the bulbs of bitterroot and camas plants were baked with heated stones, have been utilized in the region for at least 4,000 years. There is no direct evidence from the Flathead Basin, however, on the societal organization of these earliest cultures.

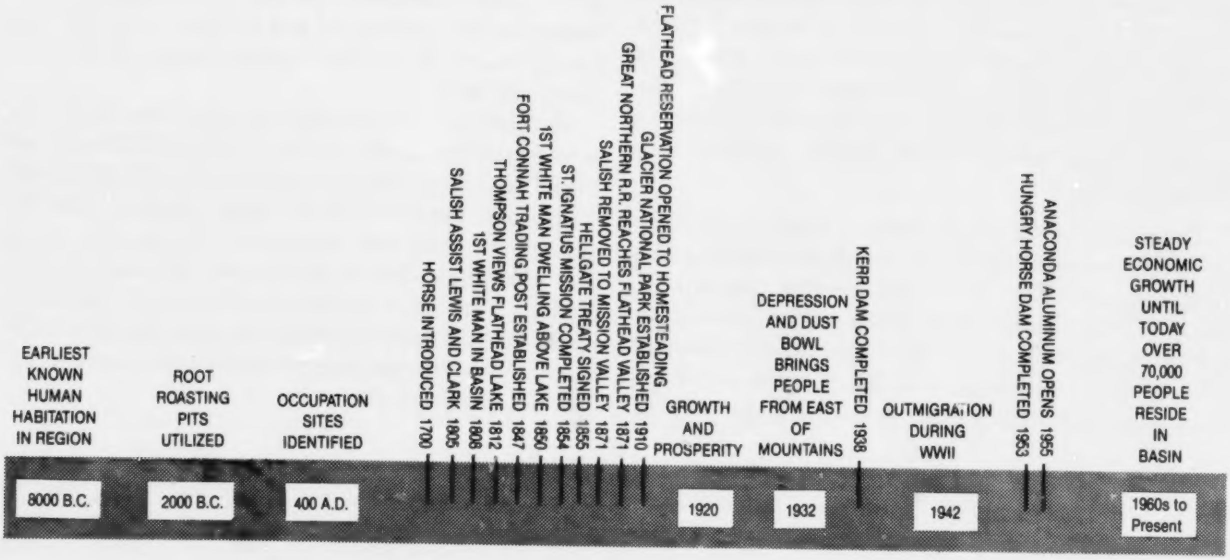
The archaeological record improves in more recent times, and researchers on the Flathead Reservation have located over 80 occupation sites, including some as old as 1,500 years. These sites, which appear to have been temporary camps rather than permanent villages, contain fire hearths, stone tools, and prey remains. The south end of Flathead Lake has proven to be a particularly rich area, providing evidence of the chronological sequence of cultural development. Pictographs were important in the Indian culture, and these sketches painted on rock walls are believed to represent the "signature" of tribal members who had attempted to communicate with supernatural forces. Painted Rocks on the west shore of Flathead Lake is one of the largest pictograph panels in Montana.

Evidence of tribal distribution in centuries just prior to the arrival of white men in the basin indicates that the Pend d'Oreille were dominant in the southern Flathead Basin, while bands of Kootenai hunted in the upper North Fork Valley. Both tribes probably used the Flathead Lake area, and both were noted for their use of bark canoes in navigating the many waterways of the region.

Trade with southern tribes brought horses to the northern Rockies in the early 1700s and altered the culture and distribution of the Indian population. Spurred by their new mobility, the western tribes undertook annual forays across the Continental Divide to hunt buffalo. These trips to the plains produced ample supplies of food and clothing, but they also sparked two centuries of war with the Blackfeet tribe. For security, the western tribes formed hunting alliances and settled into large winter encampments after the fall buffalo hunts. The Pend d'Oreille held their winter camp in the Mission Valley; the Salish tribe, formerly occupying lands on both sides of the divide, confined their permanent camp to the Bitterroot Valley in the west. Many Kootenai moved across the Rockies from the Alberta foothills into the lands lying north and west of Flathead Lake in their attempt to avoid the more numerous and better-armed Blackfeet.

FIGURE 2.8

PEOPLE AND THE FLATHEAD BASIN


EARLIEST KNOWN HUMAN HABITATION IN REGION
8000 B.C.
ROOT ROASTING PITS UTILIZED
2000 B.C.
OCCUPATION SITES IDENTIFIED
400 A.D.
HORSE INTRODUCED 1700
SALISH ASSIST LEWIS AND CLARK 1805
1ST WHITE MAN IN BASIN 1808
THOMPSON VIEWS FLATHEAD LAKE 1812
FORT CONNAH TRADING POST ESTABLISHED 1847
1ST WHITE MAN DWELLING ABOVE LAKE 1850
ST. IGNATIUS MISSION COMPLETED 1854
HELLGATE TREATY SIGNED 1855
SALISH REMOVED TO MISSION VALLEY 1871
GREAT NORTHERN R.R. REACHES FLATHEAD VALLEY 1871
GLACIER NATIONAL PARK ESTABLISHED 1910
FLATHEAD RESERVATION OPENED TO HOMESTEADING
GROWTH AND PROSPERITY
1920
DEPRESSION AND DUST BOWL BRINGS PEOPLE FROM EAST OF MOUNTAINS
1932
KERR DAM COMPLETED 1938
OUTMIGRATION DURING WWII
1942
HUNGRY HORSE DAM COMPLETED 1953
ANACONDA ALUMINUM OPENS 1955
STEADY ECONOMIC GROWTH UNTIL TODAY OVER 70,000 PEOPLE RESIDE IN BASIN
1960s to Present

University of Montana Archives, M. J. Elrod Collection, Indian Encampment at St. Ignatius

Glacier National Park Collection

White entry and the Hellgate Treaty. In 1805, the Salish Indians helped the Lewis and Clark expedition find a westward route across the Bitterroot crest, thus establishing the first Indian-whiteman contact in western Montana. In reports of his travels, Captain Meriwether Lewis grouped the Salish Indians of the Bitterroot Valley with the Flathead tribes of Oregon. Unlike some western tribes, the Salish never practiced ritual head-shaping, or flattening, on their infants; however, the "Flathead" misnomer has remained with the Salish since this earliest contact with the white man.

The skyrocketing demand for furs brought an influx of explorers, trappers, and traders to the northern Rockies during the early 1800s. Jocko Finley, a trapper who lived along the Jocko River in 1808, is the first white man known to have entered the Flathead drainage, but unrecorded others may have preceded him. The first written description of Flathead Lake dates from 1812, when Northwest Fur Company explorer David Thompson viewed the lake from a hill above the present-day site of Polson. By the 1820s, the Hudson Bay Company had established a thriving fur trade across northwestern Montana. The Indians readily adapted to the presence of the white traders and trapped large numbers of beavers and other furbearers to trade for guns, tobacco, beads, metal implements, and other goods. Fort Connah, the last of the Hudson Bay trading posts built in the United States, was established on Post Creek in the Mission Valley in 1847. By that time the buffalo robe had supplanted the beaver hat in eastern fashion circles, and Indians bartered with buffalo hides and dried meat brought back from their hunting expeditions to the eastern plains.

In 1854, Jesuit missionaries completed the St. Ignatius Mission at the southern end of the Mission Valley and began to teach white agricultural and religious practices to the resident Kootenai and Pend d'Oreille Indians on what was then called the Jocko Reserve. One year later, Governor Isaac Stevens of the Washington Territory negotiated with the Pend d'Oreille, Kootenai, and Salish tribes in an effort to place all three tribes together on one reservation. The resultant Hell Gate Treaty established the Flathead Reservation, with the tribes retaining one and a half million acres of the Mission, Jocko and lower Flathead valleys, but ceding much of present-day northwestern Montana to the United States government. The Pend d'Oreille and Kootenai Indians agreed to occupy the reservation lands immediately; however, because the Salish were reluctant to leave the Bitterroot Valley, Stevens added a key treaty provision which called for surveys of both Bitterroot and Flathead sites to determine which lands were best suited as a reservation for the Salish. The treaty also guaranteed that white settlers would be kept out of the traditional Salish lands, pending the results of the surveys.

Despite the treaty provisions, large numbers of whites began to homestead in the Bitterroot Valley. Many of the new settlers viewed the Indian presence as a barrier to further land acquisition and pressured the federal government to take action. In 1871, President Grant responded by issuing an executive order which called for the removal of the Salish people from the Bitterroot Valley, even though the surveys required under the Hell Gate Treaty had not been conducted. The next year, Salish subchiefs Arlee and Adolf emigrated with their followers to the Flathead Reservation. Chief Charlo, steadfastly insisting that the government comply with the original treaty provisions, remained in the Bitterroot Valley until 1891, when mounting pressures from white settlers and a shortage of food forced him to lead his band of about 200 Salish northward to the reservation.

Homesteading on the Flathead Reservation. The Dawes Act, passed by Congress in 1887, provided for private allotment of Flathead Reservation lands to Indians and the subsequent opening of the reservation to white settlement. A federal survey of the reservation was authorized in 1904 and completed in 1908. Land allotment began soon after, despite strong protests from tribal representatives and treaty provisions assuring the tribes perpetual title to all reservation lands.

Indians were given first choice of land, and almost 2,500 tribal members selected 80- or 160-acre tracts.

In addition to these individual allotments, the tribes retained ownership of trust lands, which included most of the forested slopes and mountainous regions of the reservation.

The federal survey designated more than one-third of the reservation (about one-half million acres) as suitable for homesteading. Settlement rights for non-Indians were initially granted through a lottery for which over 81,000 people registered; however, many of the 6,000 registrants whose names were drawn at Kalispell and Missoula did not file homestead claims within the allotted months. On November 1, 1910, homestead units not claimed through the lottery were opened to the public, prompting a frenetic midnight land rush. Homesteaders were required to stake and file their claims, establish residence, and begin land payments, which ranged from $1.25 to $7 per acre.

The brief homesteading period established the complex land ownership pattern characteristic of the Flathead Reservation. Valley agricultural lands are primarily owned by non-Indians with interspersed Indian allotments, while the high-elevation forest lands remain in tribal ownership.

Settlement of the upper Flathead Valley. The difficulty of access to the upper Flathead Valley caused early settlement there to lag behind development south of Flathead Lake. A few isolated dwellings appeared along the upper Flathead River during the 1850s and 1860s, but permanent homesteading for agriculture did not begin until the following decade. During the 1880s, a combination railroad-stagecoach-steamboat journey was the primary trade route to the upper Flathead, bringing people and goods from the populous Missoula area through the Flathead Reservation, across Flathead Lake, and into the port of Demersville on the upper Flathead River.

In 1892, the Great Northern Railroad crossed the Continental Divide at Marias Pass and reached the upper Flathead Valley. The railroad brought an influx of settlers and a means of exporting agricultural products and lumber to eastern markets. The communities of Whitefish, Kalispell, and Columbia Falls quickly developed along the railroad lines, while Demersville, several miles off the track, faded into obscurity.

By the early 1900s, over 1,400 persons were employed in logging operations and sawmills in the region. A reliable source of hydroelectric power for the Kalispell area was obtained in 1908, with the upgrading of generating capacity and transmission lines from the Bigfork Dam near the mouth of the Swan River. Glacier National Park, long recognized as a spectacular natural area by local citizens, was formally designated by the U.S. Congress in 1910, due in part to the efforts of naturalist George Bird Grinnell.

University of Montana Archives, M. J. Elrod Collection, Steamer Klondike in Yellow Bay

Twentieth century economic development. A period of good crops, high agricultural prices, and strong timber demand sparked a rapid population increase through the early 1920s; however, the boom ended under the influence of the national economic depression. During the '30s, unsuccessful dry land farmers from the Great Plains dust bowl migrated westward in large numbers. By the end of the decade, Flathead County had over one thousand "migratory" or "stranded" farm families unable to support themselves.

South of Flathead Lake, successive development of the Flathead Irrigation Project from 1910 through the mid-1930s brought over 100,000 acres under irrigation. The expanded irrigation system led to rapid growth in dairying and other farming opportunities. The construction of Kerr Dam by the Montana Power Company employed up to 1,200 people, and completion of the dam's first generating unit in 1938 greatly increased the supply of electricity available to local industries. By 1940, the population of Lake County had reached 13,490, a 41% increase in ten years.

World War II drained population from the Rocky Mountain region, as thousands emigrated to enter the armed forces or to work in wartime industries in large urban areas. Economic and population growth in the Flathead Basin following the war was initially stimulated by the rising national demand for lumber. Completion of Hungry Horse Dam on the South Fork of the Flathead River in 1953 meant increased electricity to accommodate industrial, commercial, and residential development in the region. The construction of the Anaconda Aluminum Company (ARCO) refinery in Columbia Falls in 1955 was directly related to the new availability of cheap electric power and brought many new jobs to the upper Flathead Valley. In primarily agricultural Lake County, the economy and population remained relatively static through two post-war decades.

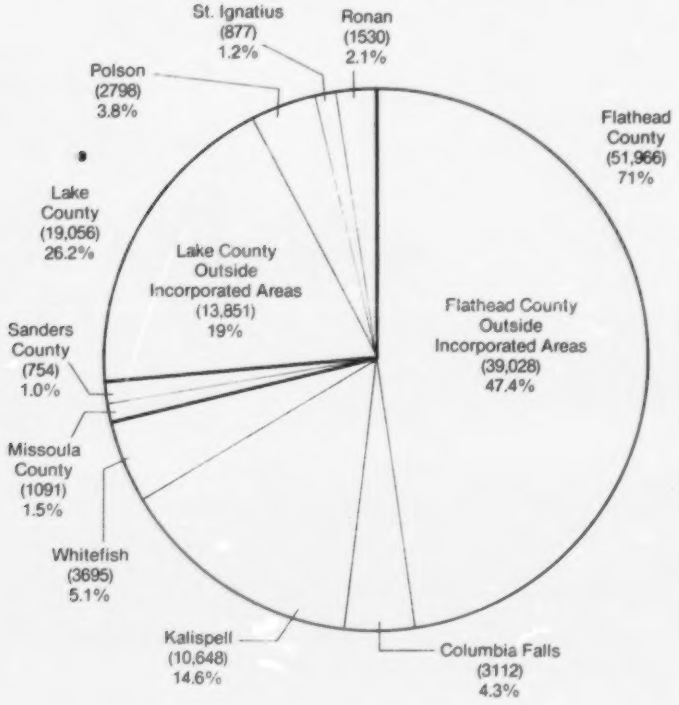
Since the late 1960s, the Flathead Basin has experienced a period of rapid population growth both north and south of Flathead Lake. Economic development in the timber, aluminum, and tourism industries has been largely responsible for this recent trend.

Population

The Flathead Basin supports 72,857 residents (1980 census figures) and embraces all of Lake County, most of Flathead County, and small portions of Missoula, Sanders, Lincoln, Powell, and Lewis and Clark counties (Fig. 2.9). Kalispell, the Flathead County seat, is the largest city with a population of 10,648. Whitefish,

FIGURE 2.9

Flathead River Basin—Population 1980



*Source: U.S. Census figures

with 3,695 residents, and Columbia Falls, with a population of 3,112, are the other major towns in the upper Flathead River Valley. The town of Bigfork and surrounding areas on the northeast shore of Flathead Lake host slightly over one thousand persons. Recent housing developments have brought thousands of residents to unincorporated areas on the outskirts of the larger cities; these areas together with West Glacier, Lakeside, Somers, Hungry Horse, Olney, and numerous other small communities, bring the total Flathead County population to about 52,000.

Lake County hosts over 19,000 persons. Polson, on the south shore of Flathead Lake, is the county seat with 2,798 residents. Ronan and St. Ignatius in the Mission Valley have respective populations of 1,530 and 877. Most of the Lake County population is dispersed among small unincorporated communities, such as Pablo, Arlee, Charlo, Elmo, and Swan Lake, or in agricultural areas. About 3,000 Confederated Salish and Kootenai tribal members live on the Flathead Reservation.

Hot Springs has 600 residents and is the only city within the Sanders County portion of the basin. The unincorporated community of Condon in the Swan River Valley lies in Missoula County.

Cultural Attractions

Higher educational institutions in the Flathead Basin are Flathead Valley Community College in Kalispell and Salish-Kootenai Community College in Pablo. The University of Montana Biological Station at Yellow Bay on Flathead Lake was founded in 1899 through the efforts of Dr. Morton J. Elrod and is the oldest field research station in the nation.

The Conrad Mansion in Kalispell and the St. Ignatius Mission are national historic buildings which draw many visitors interested in their architecture and their role in the history of the region. The Hockaday Center for the Arts in Kalispell is the focus of an active art community in the upper Flathead Valley. Both Polson and Bigfork host community theatres each summer, and both towns also serve as centers for water sports activities on Flathead Lake. The Montana Fiddler's Contest at Polson each July draws the top talents from throughout the Pacific Northwest.

On the Flathead Reservation, two tribal cultural committees work to increase awareness of Indian history, language, crafts, and traditions. Community feasts and an annual pow-wow are also part of the efforts to retain the Salish and Kootenai cultural heritage.

University of Montana Archives, M. J. Elrod Collection, Combine on Flathead Reservation

Land Ownership and Jurisdiction

A complex pattern of land ownership and jurisdiction overlies the Flathead Basin landscape. A tabulation of the major administrative authorities and their holdings indicates the variety of governmental and private entities with interests in the resources of the Flathead Basin (Table 2.5).

The Canadian portion of the Flathead Basin comprises the headwaters of the North Fork of the Flathead River. Coniferous forest covers most of the upper North Fork drainage, which is known to the Canadians as simply the Flathead Valley. The area is classified as British Columbia provincial forest and contains no permanent communities. Since 1962 when an improved gravel road first connected the Canadian Flathead to major provincial highways, government land management policies have shifted drastically. This long-neglected wilderness is now viewed as a storehouse of timber and coal, and a possible source of oil and natural gas.

The United States government controls slightly more than half of the land within the Flathead Basin, and the majority of these federal holdings are administered by the Forest Service. National forest lands consist primarily of timbered tracts on the east half of the basin and northwest of Flathead Lake. These lands are managed under a "multiple-use" concept, which rec-

TABLE 2.5

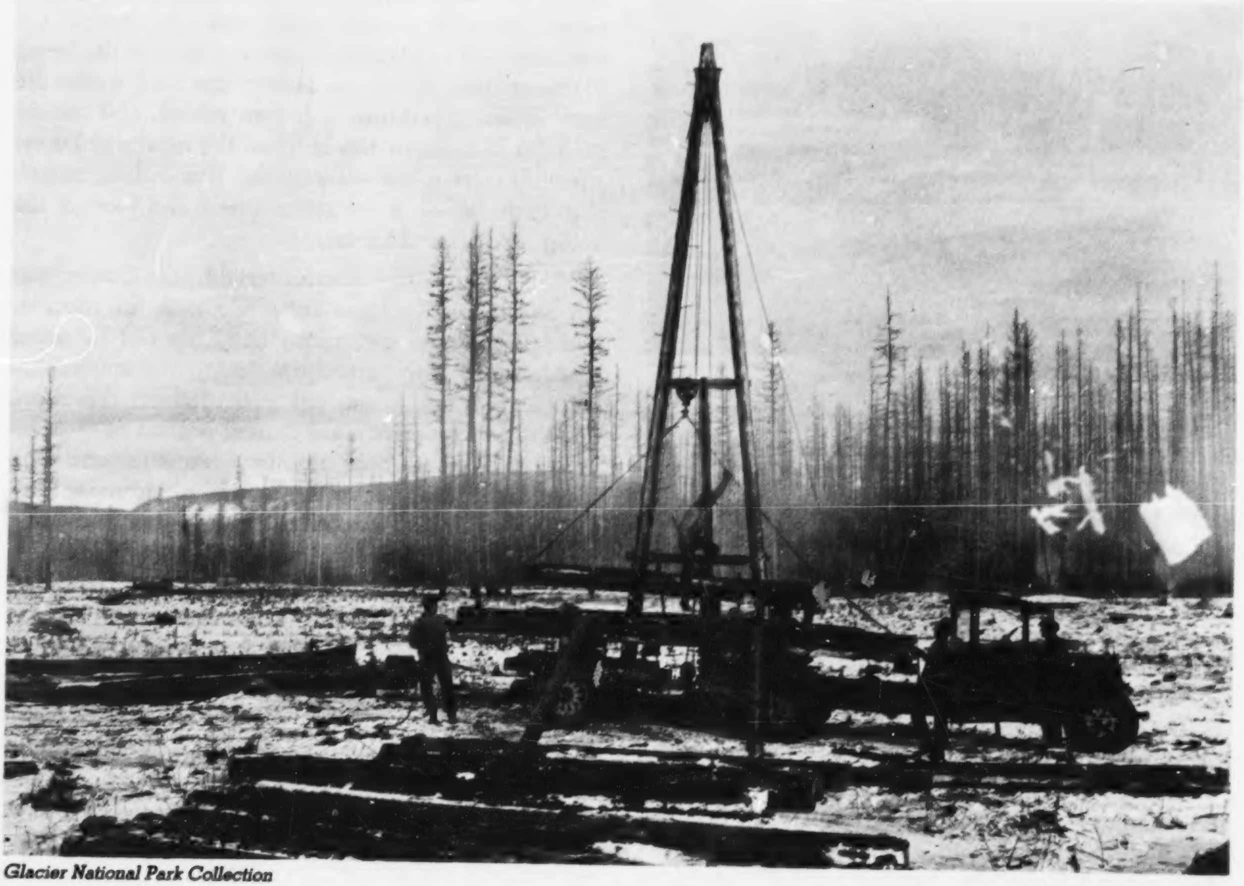
FLATHEAD RIVER BASIN LAND OWNERSHIP

U.S. Portion of Basin			
Private Lands			
Burlington Northern Timber and Lands	274,372		
other Private (includes lakes)	1,567,022		
Confederated Salish and Kootenai Tribal Trust Lands			
Mission Mountain Tribal Wilderness	89,500		
other Trust lands	484,128		
State Lands			
Department of State Lands			
Coal Creek State Forest	15,064		
Stillwater State Forest	93,815		
Swan River State Forest	38,345		
other state forest lands	41,749		
other state lands	1,722		
Department of Fish, Wildlife and Parks	3,025		
Federal Lands			
Glacier National Park	614,882		
Flathead National Forest			
Bob Marshall Wilderness	709,356		
Great Bear Wilderness	286,700		
Mission Mountains Wilderness	73,877		
Jewel Basin Hiking Area	15,000		
multiple-use management areas	1,264,999		
U.S. Fish and Wildlife Service			
National Bison Range	18,540		
Pablo Wildlife Refuge	2,500		
Ninepipes Wildlife Refuge	2,023		
Swan River Wildlife Refuge	1,576		
other federal wildlife lands	4,555		
SUBTOTAL		5,405,550	
British Columbia Portion of Basin		274,280	
			5,679,830

ognizes timber, watershed, recreation, range, and fish and wildlife as important renewable resource values, and attempts to achieve a balance between commodity and non-commodity uses. The Resources Planning Act of 1974 and the subsequent National Forest Management Act of 1976 set resource production goals and mandate long-term forest planning with public involvement.

Historically, timber harvest has been the dominant commercial use of national forest lands within the Flathead Basin. During the early 1970s, public concern heightened over the deleterious impacts of logging and road-building on watershed and wildlife values. Recent laws and agency regulations have since made timber management practices more responsive to other forest values. Interest in oil and gas leasing has skyrocketed during the last seven years, spurred by rising energy prices and hydrocarbon finds in similar geologic formations in Utah and Wyoming. More than two million acres of national forest lands within the basin have been leased or are under application for oil and gas leases. The Flathead National Forest is currently preparing a 50-year plan which will outline the future management of all national forest lands within the Flathead Basin.

Flathead National Forest lands have been in the forefront of conservationists' efforts for wild land preservation. The Bob Marshall Wilderness Area, protected under "primitive area" status by the Forest Service in 1940, was among the first national forest lands to receive statutory wilderness protection with congressional passage of the Wilderness Act in 1964. The Bob Marshall, noted for its populations of big game mammals and other wildlife, straddles the Continental Divide, with more than 70% of its one million acres lying within the Flathead Basin. Citizen action during the 1970s prompted federal legislation to establish the Mission Mountains Wilderness Area, noted for its spectacular peaks and alpine lakes, and the Great Bear Wilderness, encompassing the drainage of the wild Middle Fork of the Flathead River. Wilderness management precludes timber harvest, roads, or permanent structures. Dispersed recreation, watershed



Glacier National Park Collection

protection, and wildlife habitat are the primary uses of wilderness areas.

The west slope of Glacier National Park lies within the Flathead drainage and is under the administration of the National Park Service. Management reflects the agency philosophy of preserving natural ecosystems, while allowing compatible recreational uses. As an undisturbed example of the Northern Rocky Mountain ecosystem, Glacier was designated as an International Biosphere Reserve by the United Nations in 1974. East of the Continental Divide, Glacier shares 18 miles of the international boundary with its "sister" park to the north, Waterton Lakes National Park in Alberta, Canada. In 1932, the two parks were joined as an International Peace Park by acts of the U.S. Congress and the Canadian Parliament. Forty-seven years later, the parks were linked as the first transboundary biosphere reserve.

Glacier National Park Collection

The U.S. Fish and Wildlife Service, a federal agency with management responsibilities including migratory birds, wildlife refuges, and endangered species, has acquired a number of key wildlife tracts within the Flathead Basin. The National Bison Range, located in the southwest quadrant of the basin, maintains almost 30 square miles of pristine native grassland for big game habitat, public wildlife observation, and wildlife research. Established by President Theodore Roosevelt in 1908, the range played a major role in preserving the bison from extinction. Swan River National Wildlife Refuge encompasses key riparian habitat at the upper end of Swan Lake, while Pablo and Ninepipes refuges on the Mission Valley floor attract thousands of nesting and migrating waterfowl. The Creston National Fish Hatchery and six waterfowl production areas, including the delta marshland at the head of Flathead Lake, are additional Fish and Wildlife Service lands in the Flathead Basin.

North Fork Flathead River, British Columbia, August 1981

The Flathead Reservation, administered by the Confederated Salish and Kootenai Tribes, encompasses about one-fifth of the basin area, including the southern half of Flathead Lake and most of the lower Flathead River drainage. Half of the land within the reservation boundaries is Indian-owned, and the remainder belongs to non-Indians, the legacy of homesteading during the early 1900s. Non-Indian ownership includes all of the major towns and most of the valley agricultural lands.

Most Indian land is administered by the Confederated Salish and Kootenai Tribal Council, the reservation's 10-member governing body elected by tribal members. Timber, agriculture, water, and tourism are emphasized under current management direction, and the tribes derive a substantial portion of their income from renewable resource management. The tribes' traditional ties to the natural environment are also incorporated into land management, as evidenced by the Mission Mountains Tribal Wilderness Area, designated by the tribal council in 1982. The tribal wilderness covers the west slope of the Mission Range and abuts the national forest wilderness lying just across the Mission Crest.

Private Indian-owned allotments comprise 4% of the reservation. These lands are under the jurisdiction of the federal Bureau of Indian Affairs, rather than the tribal council. Both private allotments and tribal lands are held in trust for the Indians by the United States government under treaty provisions.

The State of Montana has three major holdings within the basin—the Stillwater, Coal Creek, and Swan River state forests—along with numerous mile-square tracts scattered throughout the basin. These state lands are managed under sustained-yield guidelines, with an additional mandate to generate maximum revenues to support the Montana public school system. Timber sales, oil and gas leases, and grazing leases provide most of the school trust revenues.

Lands purchased by the Montana Department of Fish, Wildlife and Parks fall under separate management constraints, with emphasis on wildlife habitat and recreation. These properties include wildlife management areas, fishing access sites, campgrounds, and numerous shoreline parks on Flathead Lake and other area waters. Wild Horse Island, a 2,200-acre state park in Big Arm Bay of Flathead Lake, is renowned for its scenic beauty and its herd of bighorn sheep.

The Flathead Basin contains portions of seven counties, with Flathead County in the north and Lake County in the south embracing most of the land area and population. County governments serve as an extension of state government and can only exercise authority which has been specifically delegated by the legislature. Among their prescribed duties, counties are responsible for regulating development on private land outside of incorporated communities. County officials review proposed new subdivisions for sanitation and land-use considerations, with authority for subdivision approval vested in county commissions. A comprehensive plan completed in 1978 partitioned Flathead County into recommended land-use areas; however, a recent court ruling has raised legal questions about the plan and a revision is underway. Lake County is also in the process of preparing a comprehensive land-use plan. For both counties, zoning regulations would have to be adopted to give the comprehensive plans legal force.

Incorporated municipalities are chartered by the State and, unlike counties, possess the authority to pass and implement local laws and ordinances. Most cities have instituted zoning restrictions to control urban land use. Municipal planning and zoning authority can extend beyond the immediate city limits. Kalispell, Whitefish, Columbia Falls, and Polson are involved in joint city-county planning efforts.

The major private landholder in the Flathead Basin is Burlington Northern Timberlands, Inc., which owns over 274,000 acres of primarily forested land. These lands were acquired as part of the large railroad land grants made by the federal government in the late 1800s. Burlington Northern lands are managed for timber production, and public recreational access is generally permitted. Many Burlington Northern holdings are in a checkerboard pattern with national forest lands west of Kalispell and in the Swan River Valley. Other corporate landowners with significant holdings include Champion International and Stoltze Land and Lumber, both forest products corporations. Total private land ownership in the Flathead Basin is about one and a half million acres, or slightly over one-fourth of the land area.

Resource Management Overview

The complexities of land ownership in the Flathead Basin create inherent difficulties for natural resource managers. Arbitrary survey lines apportion watersheds between agencies with contradictory mandates. Management goals can be compromised by the actions of an adjacent landowner because the environmental impacts of development extend beyond property boundaries. Communication between land managers is too often initiated in response to a crisis, rather than as a planned approach to resource management.

The most publicized resource controversies within the Flathead Basin center on the British Columbia portion of the North Fork. In the southeast corner of the Canadian Flathead, lands once slated for national park status have been opened to logging to combat an infestation of mountain pine beetles. Extensive clearcuts and the lack of reforestation have raised concerns over potential erosion within the Akimina and Kishenehn drainages, which have historically provided some of the region's most important habitat for fish and wildlife.

Proposed site Cabin Creek Coal Mine, Flathead Valley, British Columbia, South Hill, August 1981

Also within the Canadian Flathead, the Sage Creek Coal Company is proposing to develop twin open-pit coal mines at Cabin Creek, six miles north of the international border. Development at the Cabin Creek site is viewed as a serious threat to air and water quality, fisheries, and related values, not only in British Columbia, but also in the Flathead drainage in Montana. Four additional major coal deposits have been located within the Canadian portion of the North Fork, and exploration for oil and gas is proceeding.

Proposed site Cabin Creek Coal Mine, Flathead Valley British Columbia, North Hill, August 1981

Although such large-scale development proposals threaten serious changes in the region, the British Columbia governmental system has few built-in provisions to preserve environmental integrity. The province does not rely on a well-developed body of regulatory law or direct public access to administrative agencies, two avenues available to lessen environmental impacts under both state and federal jurisdictions in the United States. A multi-stage review procedure does exist to provide for a comprehensive review of coal mine development proposals, but the Parliamentary system depends primarily upon the electoral process to effect policy changes. During recent decades, political decisions have emphasized the need to develop the province's largely untapped natural resource base, and environmental protection has not generally received a high priority in land-use decisions.

The early 1980s, however, have seen an increasing concern about the potential effects of development on natural values in the Canadian Flathead drainage. The specter of widespread coal mining prompted the B.C. Ministry of the Environment to prepare a strategic plan for conserving fish and wildlife populations, air quality, and water quality and quantity. Communications between the State of Montana and the British Columbia provincial government have improved markedly. Montana was invited to submit official comments on the coal mine proposal, and many of the technical recommendations on ways to mitigate adverse impacts have been incorporated into British Columbia's evaluation of the project.

In the event that coal mining proceeds, the water quality provisions of the Boundary Waters Treaty between the United States and Canada may be invoked. The key treaty sections establish the International Joint Commission, a quasi-judicial body of three Americans and three Canadians who can investigate and recommend solutions to transboundary water pollution problems. The commission, however, initiates investigations only upon the request of both governments and lacks statutory authority to enforce the anti-pollution obligations in the treaty. As a result, Montanans concerned about the adverse water quality impacts of the Canadian coal mines have only a tenuous legal recourse, and must rely primarily upon the good will of British Columbia officials.

Canadian interest in natural resource development thus underscores the need for international cooperation to protect the Flathead watershed. The future of the region will in part depend on how well the recent new British Columbia governmental concern for the environment will mesh with an institutionalized emphasis on resource extraction.

Management of national forest lands within the Flathead Basin in Montana continues to inspire vigorous debate between interest groups. Allocations of land for timber harvest, road-building, oil and gas leasing, and preservation of wildlife habitat and wilderness often polarize public opinion, with some groups arguing that development will not impair natural values and others contending that key environmental attributes will be jeopardized. Judgments about the

REPORT FOR
INSPECTION
TO

Looking South, North Fork Flathead River at Canadian Border

Abandoned oil well Couldry Creek, B.C. 8-7-81

cumulative effects of resource development by the Forest Service, the State of Montana, and other major landowners throughout the basin have remained speculative, pending reliable information on the physical and biological processes which maintain the values of the Flathead Lake and River system.

Jurisdictional complexities have impeded environmental protection efforts by city, county, and tribal governments within the Flathead Basin. Recent population growth brought unprecedented residential and commercial development to unincorporated lands on the edge of the larger cities. County governments, historically constituted to meet rural needs, have suddenly been faced with the problems of providing services to areas of high population density. Limitations on individual land-use prerogatives through zoning have been less well accepted by rural landowners than by urban property holders; as a result, county governments have often been unable to channel development to environmentally desirable sites. Moreover, many land splits are exempt from review because tracts are larger than 20 acres or because of legal provisions allowing certain subdivisions without review. Scattered housing development on river flood plains, agricultural lands, and big game winter ranges have had predictably adverse impacts on water quality, farm production, wildlife populations and open space.

On the Flathead Reservation, the interspersed Indian allotments, tribal trust acreage, and non-Indian lands have added uncertainty to both tribal and county planning efforts. Indian lands are exempt from Lake County planning jurisdiction and, conversely, tribal regulations do not apply to non-Indian tracts. Rural residents have consequently been reluctant to accept land-use restrictions which might be ignored by neighboring landowners.

Cooperative relations between Lake County and the Confederated Salish and Kootenai Tribes would also enhance the effectiveness of shoreline management for Flathead Lake. In late 1982, the U.S. Supreme Court let stand a lower court decision granting the tribes the authority to regulate docks, dredging, and other development along the lakeshore within the reservation boundaries. The court ruling, however, did not alter county responsibility for land use within a 20-foot-wide strip immediately above the high-water mark. This split jurisdiction has prompted recent overtures from tribal and county officials to coordinate permitting procedures so that common lakeshore objectives—including the prevention of erosion and the protection of water quality, scenic values, and fish and wildlife habitat—will not be compromised through conflicting actions or regulations.

Conservation of water quality in Flathead Lake presents the greatest management dilemma, with federal, state, provincial, tribal, county, municipal, and private land-use decisions in the upper Flathead drainage all influencing conditions downstream. Although a multitude of regulations govern local land uses and water quality impacts, no agency is specifically charged with conserving water quality or monitoring the cumulative effects of land uses on Flathead waters. As interest increases in developing the natural resources of the Flathead Basin, the potential for damage to Flathead Lake water quality also grows. A coordinated effort by the various jurisdictions appears necessary to prevent deterioration of the lake and thus preserve an important element of the quality of life of basin residents.

Somers Bay, Flathead Lake

CHAPTER III
FLATHEAD BASIN ECONOMY

University of Montana Archives, M. J. Elrod Collection, Bigfork

Montana Travel Promotion Unit

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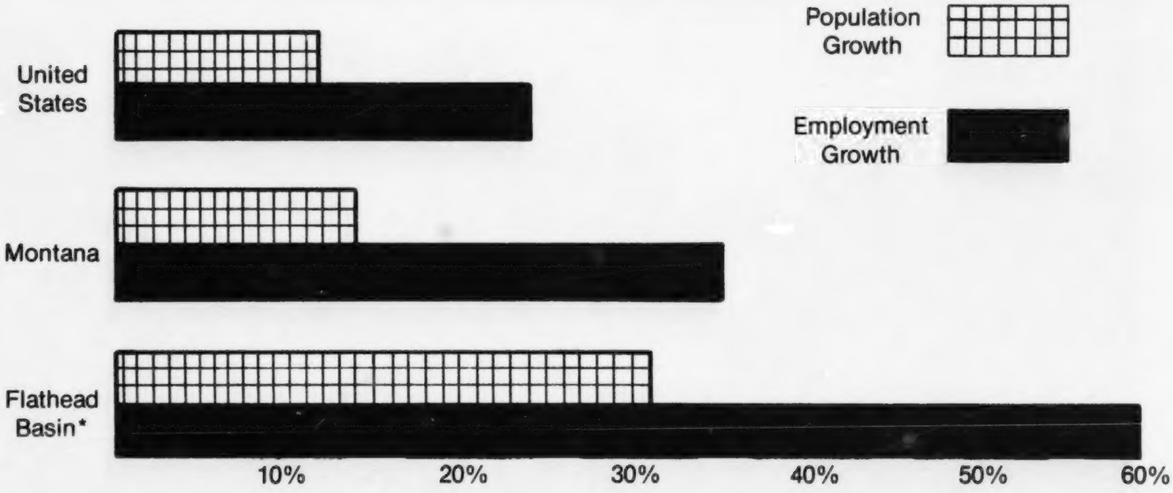
The economy of the Flathead Basin is based on natural resource development. Thousands of residents make their livelihoods by producing agricultural goods from the fertile valley soils, wood products from the vast forests, hydroelectric power and resulting industrial output from the abundant water supply, and tourist trade from the spectacular natural environment. Employment opportunities in these resource-based industries are complemented by a wide variety of jobs in retail trade, services, government, and other supporting sectors.

During the 1970s, the Flathead Basin experienced a period of unparalleled economic growth. Total employment increased by about 60%, almost double the employment growth rate statewide and nationwide (Fig. 3.1). This rise in employment was accompanied by a 31% increase in population, most of which was caused by immigration in response to new job opportunities. Only three Montana counties had higher population growth rates than either Flathead or Lake counties during the last decade.

Because economic activity strongly influences both the cultural and natural environment, the Flathead River Basin Environmental Impact Study sponsored an intensive investigation of the regional economy. Researchers focused on the forces behind the recent economic surge, the factors now controlling economic activity, and the prospects for future economic growth in the diversified Flathead Basin economy. Projections also outlined how economic trends will affect employment, population, and the fiscal conditions of local governments in the region.

FIGURE 3.1
Comparative Growth
(1970-80)



*Sources: U.S. Bureau of the Census, 1980 Census of Population and Housing, Advance Reports, Final Population and Housing Unit Counts, Montana and United States Summary, issued February and April 1981 respectively.

Montana Department of Labor and Industry, *Montana Employment and Labor Force*, February 1981.

U.S. Bureau of Labor Statistics, *Monthly Labor Review*, Vol. 104, No. 2, February 1981.

*Employment data not available for the portions of Sanders and Missoula Counties in the Flathead Basin.

Local Economic Performance

The status of a regional economy depends on employment opportunities and worker income, which in turn reflect the vitality of local businesses. When a lagging demand for goods reduces both industrial production and profits, fewer jobs are available and there is less money to fuel the economy. Positive economic conditions are characterized by a strong demand for locally produced goods and resulting high employment and income levels.

The "export base theory" of economics is helpful in assessing the rapid growth in the Flathead Basin economy during the last decade. Briefly, the theory states that all wealth is generated by the exchange of local goods for non-local dollars. For example, when a Flathead mill sells lumber to an out-of-state contractor, the money supply in the basin increases. Economic growth based on this new money is possible, and industry, workers, and other businesses will benefit. On the other hand, when goods or services are exchanged locally, wealth is not increased and the economy overall is unaffected.

Economists distinguish basic industries, those that bring new money into an area, from non-basic industries, those that simply cycle existing wealth through the community. Typically, basic industries produce or refine goods which are exported from the region in exchange for dollars. Wood products, agriculture, and manufacturing are in this category. Non-basic industries, such as most retail sales and services, rely on local money to generate jobs and profits, but do not increase the total money supply of the region.

Some sectors of the economy have both basic and non-basic components. Municipal government is generally a non-basic industry because it redistributes local tax money to pay operating expenses; the federal government is a basic industry whenever programs or agencies bring funds into a community for salaries, grants, construction projects, or purchases of goods and services. Hotels and restaurants serve local patrons and visitors from outside the region, but only the latter contribute new wealth to the community and constitute a part of the basic travel-and-tourism industry. Similarly, retail stores serve a mixed clientele. The majority of their business is non-basic from local residents, but a small part is basic from shoppers who come into city trade centers to find products unavailable in outlying areas.

The distinction between basic and non-basic industries is important because only the basic sector can cause economic and employment growth. The outside dollars captured by a basic industry initially accrue to workers, management, and investors in the form of wages and profits. A large share of this money is then cycled through the local economy to provide investment capital for business ventures, to purchase goods and services, and to provide government services. This flow of money, in turn, supports jobs in the non-basic sector.

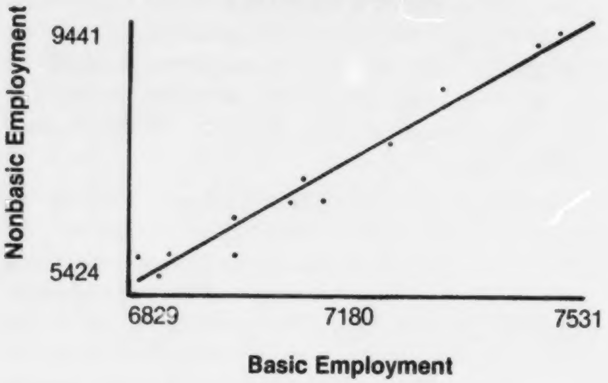
The ratio of non-basic jobs to the basic jobs supporting them is termed the "employment multiplier". As would be expected, higher paying basic jobs pump more money into the economy and thus have higher employment multipliers. For example, a job in the wood products industry supports almost two other jobs in the community; a basic job in the lower paying tourism industry supports slightly less than one other job in the non-basic economic sector. Viewed in terms of economic growth, the addition of one permanent basic job will usually add a total of two to three new jobs to the local economy.

Population size is also linked to basic employment and Montana communities consistently have about 5.5 people for each job in the basic sector. The holder of the basic job and dependent family members are one component of this figure; the workers and dependents attached to the derivative, non-basic jobs complete the employment-population equation. Migration to areas with new employment opportunities and emigration from areas where basic employment has declined are responsible for this stable ratio of basic employment to population size in Montana.

The export base theory and the employment and population multiplier effects have several implications for understanding the operation of a local economic system. First, the majority of jobs will be in the non-basic sector because most basic jobs support more than one non-basic position. Second, the non-basic jobs exist in response to the revenues generated by the basic industries, so the performance of the basic industries determines whether the economy will grow or decline. Finally, regional population trends are closely linked to the status of basic economic industries.

Export base theory provides an excellent framework for analyzing the economy of the Flathead Basin (Fig. 3.2). The limited number of basic industries is readily defined, and each industry can be evaluated by its importance in generating local jobs and income. The array of non-basic industries can properly be grouped together as a single economic sector that reflects, rather than influences, economic conditions.

FIGURE 3.2
Nonbasic/Basic Employment Flathead County



Source: Derived from U.S. Bureau of Economic Analysis, Regional Economic Information System, unpublished employment data, 1967-1979.

As reviewed below, export base theory clearly explains the rapid economic growth that occurred in the Flathead Basin during the 1970s. Both population and employment trends were linked to the performance of the region's basic industries. Export base theory also provides a sound method of predicting the future of the Flathead Basin economy, based on the outlook for the leading basic industries.

Basic Industries in the Flathead Basin

Five major industries dominate basic economic activity in the Flathead Basin (Table 3.1). The wood products industry is the largest economic factor, providing about 28% of the basic-employment income regionwide. Major components of the industry include logging firms, sawmills, two plywood factories, and a particle board plant, along with numerous small house-log and post-and-pole operations. In 1979, 42% of the timber harvested within the basin came from national forest lands, 37% from private lands, 13% from the Flathead Reservation, and 8% from state lands. This distribution reflects an increasing harvest from corporate timber lands in the basin and a decline in the cut from national forest lands over the past decade. Five North Central states (Minnesota, Iowa, Nebraska, and the Dakotas) purchase almost half of the lumber and plywood exported from western Montana (Table 3.2). Buyers in Montana and nearby Rocky Mountain states account for another one-fourth of the annual cut, while the remaining quarter of western Montana lumber and plywood is distributed to many regions across the country.

TABLE 3.1
Relative Importance of Basic Sectors (Flathead and Lake County Total) 1978

	Percentage of Total	
	Unadjusted Basic Employment	Income Adjusted
Agriculture	20.8%	20.0%
Mining	0.2	0.3
Construction	4.7	5.1
Wood Products	23.2	28.4
Primary Metals	12.3	18.2
Other Manufacturing	2.5	2.4
Transportation/ Communications & Utilities	5.2	8.1
Trade and Services	11.0	8.3
Government	0.2	0.2
Tourism	19.9	9.1
Total	100.0%	100.0%

Source: Montana Department of Administration, MASS II Model.

Note:* Income adjustments are based on state averages. These adjustments appear to overstate the local importance of agriculture. This issue is discussed later in the section 5.1. The reader is advised to review Table 2.20 and Figure 5.1 for additional comparisons in the F.R.B.E.I.S. Economic Study. 1982.

TABLE 3.2
Shipment of Lumber and Plywood From Manufacturers in Flathead, Lake Lincoln, and Missoula Counties, 1976

Market Area	Value of Lumber and Plywood (Thousands of Dollars)
Montana	$ 3,776
Rocky Mountain	$ 3,485
Far West	$ 1,743
North Central	$12,779
South	$ 2,614
Northeast	$ 1,452
Export	$ 871
Unknown	$ 2,323
Total	$29,043

Source: Bureau of Business and Economic Research, University of Montana, Montana Forest Industries Data Collection System.

Primary metals production, comprising the ARCO Aluminum plant in Columbia Falls, is the second largest contributor to the Flathead Basin economy. Although the industry's 1,200 employees at full production constitute less than one-eighth of the basic work force, their high-paying jobs constitute almost one-fifth of the basic sector income. Aluminum refining requires tremendous amounts of electricity, and inexpensive hydroelectric power was the magnet that brought ARCO Aluminum to the Flathead Basin. Alumina is shipped from Everett, Washington, to Columbia Falls, where the concentrate is refined into ingots. Ingots from the plant are then shipped to factories in the southeastern United States, where finished aluminum products are manufactured. At peak capacity, the ARCO plant can produce 180,000 tons of aluminum a year.

A diverse agricultural industry in the Flathead Basin produces beef, dairy products, hay, grains, cherries, apples, seed potatoes, Christmas trees, trout, and other farm goods, with cash receipts totaling about $50 million annually (Table 3.3). Lake County ranks 20th among Montana's 56 counties in the value of its agricultural products; Flathead County, with a predominance of mountainous and timbered lands, ranks 38th. During 1978, about 2,260 workers were employed in agriculture, which ranks second to wood products in regional basic employment, and ranks third in worker income, behind wood products and aluminum refining.

Agriculture is the foundation of the many small communities scattered throughout the basin, particularly in Lake County where industrial development is limited. Non-basic business opportunities dependent on agriculture include farm implement dealers, feed suppliers, and transportation firms. In recent years, income from farming and ranching has provided an important measure of stability to an economy subject to large fluctuations in timber demand. Many rural families largely supported by non-agricultural jobs continue to operate small-scale farms, ranches, or orchards. This dedication to agricultural values is an important part of the social fabric of the Flathead Basin and also helps maintain open space, wildlife habitat, and visual attractiveness.

Tourism and travel provide about 20% of total basic employment in the region. This figure is considerably higher than the average for other Montana locations, reflecting the drawing power of the scenic and recreational attractions of the Flathead Basin. Glacier National Park annually hosts over one and a half million visitor days annually, while Flathead Lake receives about half as many visitors as Glacier. During winter, the Big Mountain resort north of Whitefish draws thousands of skiers to its numerous downhill runs.

Statewide, slightly over half of travel revenues are generated by tourism, while the remainder results from business trips and expenditures by persons passing through Montana on the way to other destinations. Jobs in the tourism industry are primarily in service

TABLE 3.3
Important Agricultural Products Flathead and Lake Counties (Cash Receipts 1979)

	Flathead	Lake	Total	Percent of Total
Wheat	$ 1,971,100	$ 1,314,200	$ 3,285,300	6.7%
Barley	3,179,400	1,545,900	4,725,300	9.7%
Oats	94,200	158,700	252,900	0.5%
Hay	3,427,900	6,470,100	9,898,000	20.3%
Livestock	8,951,300	19,602,500	28,553,800	58.6%
Cherries	n/a	n/a	n/a	n/a
All Other	n/a	n/a	n/a	n/a
Total	$15,877,300*	$28,385,900*	$48,727,300	100.0%

Source: Montana Agricultural Statistics, Montana Department of Agriculture.

*Note: Statistical Discrepancy

economic surge in the Flathead Basin. Almost 1,300 new jobs were created over the 10-year period, and about 22% of employment and population growth can be traced to this basic industry. An estimated two-thirds of this expansion can be attributed to tourism, reflecting an increased American population with greater leisure time and a resurgent interest in the outdoors. Expansion in retail trade was the final major contributor to basic economic growth. As the regional population increased in response to the new basic job opportunites, local merchants expanded their inventories and new businesses opened. The availability of more goods, in turn, drew outside consumers into the Flathead Basin to spend their trade dollars.

While other basic economic sectors were advancing, employment in agriculture declined by about 12%. A trend toward larger, more mechanized operations, combined with subdivision of farms and ranches for housing, eliminated over 300 agricultural jobs. Federal government and light manufacturing were two other basic industries that lost employment during the 1968-1978 period.

Job growth in non-basic sectors tracked the upsurge in basic employment. During the 10-year period ending in 1978, about 7,000 new jobs in wholesale and retail trade, various services, construction, and local government were created to capture some of the new wealth and to serve the expanded population (Table 3.5).

Unemployment and Per Capita Income

While total jobs in the Flathead Basin rose dramatically from 1968 to 1978, unemployment rates remained at 7-10%. This level was consistently one to three points higher than the Montana average, even though employment growth in the Flathead far outstripped the rest of the state. This apparent paradox relates to the pattern of in-migration. As more jobs became available, the influx of job seekers kept the unemployment rate relatively high.

The seasonality of many jobs in the region also contributes to high unemployment rates. Logging, construction, agriculture, and tourist-related services are all characterized by peak employment levels in summer and reduced job activity in winter. As a result, total employment is up to 14% higher in summer than in winter in Flathead County. Overall, seasonal layoffs add about two points to the unemployment rate regionwide.

Despite a decade of record earnings for workers, the average income per resident in the Flathead Basin climbed at a slower rate than the statewide average. Lake County resident realized a 22% increase in real (adjusted for inflation) income from 1968 to 1978, while real per capita income in Flathead County rose 27%. For the same period, the Montana average was a 32% gain in real per capita income. This relative decline in per capita income related to the impacts of in-migration and seasonality. As job expansion created

TABLE 3.5
Flathead Basin Employment

	1968	1978	Change	Percent of Change
Farm Related	2618	2270	-348	-4.1%
Mining	17	22	5	0.0%
Construction	798	1445	647	7.7%
Manufacturing	4030	4425	395	4.7%
Transportation & Utilities	1286	1511	225	2.7%
Wholesale—Retail Trade	3280	5434	2154	25.5%
Finance & Real Estate	375	861	486	5.8%
Services	1976	3989	2013	23.9%
Nonfarm Proprietors	2024	3526	1502	17.8%
Government	3441	4800	1359	16.1%
Total	19,845	28,283	8438	100.0%

Source: U.S. Bureau of Economic Analysis, Regional Economic Information System.

sectors, such as lodging, food preparation, recreational services, and retail trade, and wages are typically about half of those paid in other basic industries. Tourist activity in the Flathead Basin is concentrated in the summer months, although interest in winter skiing is increasing. When tourism-based employment is adjusted for its low wage scale and the seasonal employment pattern, the industry ranks fourth in the region, providing about 10% of all basic earnings.

Kalispell's importance as a retail and service center is another significant aspect of the basic economy. Trade dollars brought in by consumers from other areas of western Montana and from Canada supply an estimated 8% of the basic income in the region.

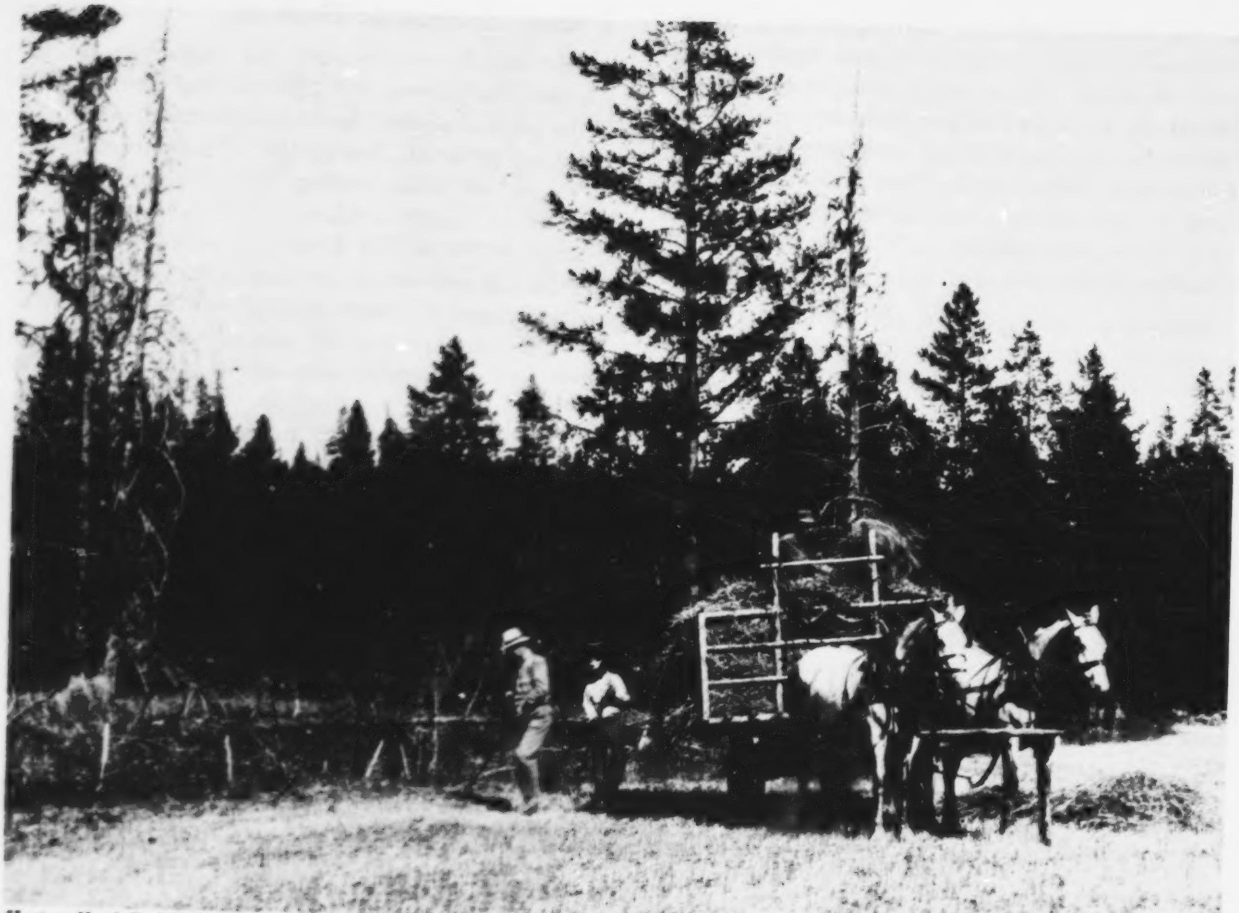
Construction, transportation, communications, and utilities together make an important contribution to basic economic activity in the Flathead Basin; mining and light manufacturing are both minor basic industries in the region. Government rounds out regional basic employment, with about half of the many government jobs supported by local funds and the other half, particularly jobs with the Forest Service and National Park Service, a part of the basic economy.

Recent Economic Growth

The rise in employment and population in the Flathead Basin from 1968-1978 can be traced directly to the performance of the basic industries (Table 3.4). During that decade, the number of basic jobs rose by 15%, and all of the leading basic industries, except agriculture, shared in this growth. Primary metals production at the ARCO Aluminum plant experienced the greatest expansion, accounting for 40% of the increase in basic earnings regionwide. Plant modernization led to the hiring of 230 new workers in 1977, and about half this number were added to the permanent work force after construction activities were completed. The wood products industry provided 154 new basic jobs from 1968-1978, generating about 30% of the economic growth in the basin. Expansion in wood products resulted from two primary factors: the increased use of wood residues for products such as particle board, and the strong construction demand for lumber and plywood, as members of the post-World War II "baby boom" generation came of age and entered the housing market. Growth in tourism and travel was the third most important factor in the

TABLE 3.4
Basic Employment by Industry, 1968-1978

	1968 Employment	Employment Change 1968-78	1978 Employment	1978 % of Basic Employment	% of Basic Earnings 1978
Wood Products	2377	154	2531 (1979)	23.2	28.4
Primary Metals	1100 (1970)	236	1336	12.3	18.2
Agriculture	2570	-308	2262	20.8	20.0*
Tourism	870	1288	2158	19.9	9.1
Trade and Services	N/A	348	N/A	11.0	8.3
Transp/Comm/Utilities	N/A	-122	N/A	5.2	8.1
Construction	N/A	169	N/A	4.7	5.1
Other Manufacturing	N/A	-127	N/A	2.5	2.4
Government	703	-207	496	[0.2]	[0.2]
Mining	17	5	22	0.2	0.2



Haying, North Fork Flathead River Valley, photo by Mildred Leo Clemens

new income, this wealth was being divided among an ever-larger number of people migrating to the region. Thus, average earnings remained at a fairly stable level. The seasonal nature of many jobs in the region further depressed per capita income, because many workers received little or no income for several months. Seasonality, especially in western Montana, has been cited as a major reason why per capita income in the state is about 12% below the national norm.

Per capita income statistics reveal a sharp difference between Flathead County (1% above the Montana average) and Lake County (27% below the statewide average). A shortage of job opportunities on the Flathead Reservation is one major reason for the lower per capita income of Lake County residents. Unemployment among Indians on the reservation has been estimated at 30-50% in recent years. Also, Lake County jobs are concentrated in lower paying sectors, with agriculture, retail trade, and service employment providing the majority of jobs.

Population Growth

As the Flathead economy grew during the 1970s, the local population followed suit. Between the 1970 and 1980 censuses, the basinwide population increased by 31%, from 55,800 to 72,900. In-migration accounted for 12,800 new residents during the decade; in contrast, the region's natural population growth (births minus deaths) was only 4,300 during the same period.

Schoolhouse; North Fork Flathead River Valley, photo by Ralph Thayer

Available employment, rather than attractive environment, was clearly the major inducement for Flathead Basin immigration. Population increased at a rate directly attributable to job expansion and, in Flathead County, the percentage of retirement-age individuals was equal to the state average. In Lake County, retirement in-migration may have contributed a small amount to population growth, as the county has a greater proportion of older residents than the statewide average.

Population growth during the 1970s occurred mainly in the unincorporated areas, rather than in the existing cities. The population of Kalispell, for example, rose by only 1%, while the county population outside of the larger city limits increased by 50%. Similarly, Polson realized a 14% increase while unincorporated areas grew by 43%.

Economics of Local Government

Municipal and county governments in Montana rely on several sources of revenue, some generated locally and others distributed by state and federal agencies. Statewide, property taxes constitute 42% of total revenues for county governments, 28% for cities, and 19% for towns. Tax payments are determined by the assessed property value multiplied by the rate of taxation. Where property values are high, lower than average tax rates (mill levies) can be applied to produce necessary property tax revenues. On the other hand, low property values often necessitate high mill levies to meet revenue requirements of local governments. The remainder of local revenues include fees, licenses, fines, and public utility charges. Non-local revenues consist of intergovernmental transfers, which became increasingly important during the 1970s with the growth of federal and state grants-in-aid and state shared taxes.

The increased residential use of rural lands, together with the growing commercial and industrial activities in the cities, created a need for expanded city and county services in the Flathead Basin during the 1970s. Expenditures for public safety, utilities, roads, and general government operations increased sharply, driven by population and inflationary pressures. In most jurisdictions, the revenue burden on local taxpayers also grew rapidly. All jurisdictions in the basin, however, had greater income than expenses from 1975 through 1980, a condition largely attributable to the rise in intergovenmental transfers.

Repairing Polebridge, North Fork Flathead River, Glacier National Park Collection

Based on data compiled for fiscal year 1980, the Flathead County government spent 45% more money per resident to provide services and to maintain government institutions than other Montana counties with comparable populations. Residents' payments to support county government were more than double the Montana average. Property taxes made up about half of the county income, reflecting above average property values and an 18% higher than average mill levy. Lake County operating expenses per resident were below average for Montana counties with comparable populations. Property values in the county were also low, however, and the property tax rate was 34% above average to generate adequate local revenues.

In Kalispell and Whitefish, 1980 property values were considerably higher than in similar-sized Montana cities; as a result, lower than average mill levies were applied to generate revenues. Both cities spent above average amounts for operating expenses. Columbia Falls imposed the highest mill levy of any jurisdiction in the Flathead Basin. With its much lower than average operating expenses, Columbia Falls took in considerably more local revenue than its total expenditures during 1980.

The municipal governments of Polson, Ronan, St. Ignatius, and Hot Springs all had lower than average operating expenses. Polson, Ronan, and St. Ignatius imposed lower than average mill levies, but Hot Spring had a relatively high property tax rate to compensate for low property values.

Transfers from federal and state sources provided from 40% to 60% of city and county government revenues during 1980. These funds helped maintain the fiscal integrity of Flathead Basin governments; however, dependence on non-local funding sources has made some local governments susceptible to political events beyond their control. Federal economic policies instituted in 1981 have already drastically reduced many revenue-sharing programs, and as a result local governments have clearly entered a period of fiscal austerity.

During 1980, Flathead County generated local revenues in excess of operating expenses, and thus did not rely on intergovernmental transfers to meet recurring expenses. Lake County expenses exceeded local revenues, although to a lesser degree than average for comparable Montana counties. From 1977 to 1980, both counties had built up sizable budget surpluses based on state and federal funding programs.

Kalispell and Whitefish relied less on intergovernmental expenditures than did similar municipalities statewide. Columbia Falls, with its high mill levies, more than met all of its operating expenses with local revenues during 1980. Polson, Ronan, and St. Ignatius all generated local revenues near or above the level needed to pay expenditures. Hot Springs relied on intergovernmental revenues to pay recurring expenditures more than any other city or town in the Flathead Basin.

Economic and Population Outlook

The economic boom rocking the Flathead Basin during the 1970s has subsided in recent years. Growth continues in many economic sectors, but at a slower rate than before; other industries are experiencing stable or declining levels of employment and earnings.

The direction of the regional economy will determine whether business ventures might succeed and whether workers will enjoy ample job opportunities. Knowledge of economic trends will provide insight on likely population levels and will thus allow government officials to anticipate new demands on municipal services and on the Flathead Basin environment.

To clarify the economic outlook, the Flathead River Basin Environmental Impact Study sponsored a regional forecast through the year 2000. The forecast assessed the key factors influencing each basic industry, including local trends, national economic conditions, energy prices, market factors, and the availablility of raw materials. High, moderate, and low economic growth scenarios were developed for each basic industry, and resulting employment levels were projected. The response in non-basic jobs to the change in numbers of basic jobs was then calculated, based on the multiplier effect (i.e., the number of non-basic jobs supported by each basic job). Finally, population levels were derived from the employment projections, and forecasters assessed whether people will be migrating to the region to fill new jobs or emigrating in search of jobs elsewhere. The following discussion details basic employment trends through the year 2000, as projected by the moderate, or "best guess", scenario of regional economic performance (Table 3.6).

Projections of basic industry performance. As the single most important basic sector, the wood products industry will strongly influence future economic growth in the Flathead Basin. During the 1970s, the industry was a key factor in the region's economic growth; since then, timber employment has dropped significantly. Projections for this volatile industry must consider timber supply and demand, utilization of the

TABLE 3.6

Employment Projections (Flathead and Lake Counties)

	1990	2000	Gain (1980-2000)
High	3063	3564	1002
Medium	2796	3029	467
Low	2529	2495	-67
Trend	2802	3026	464

1979 = 2531

Source: Derived

wood resource, and the relation between wood product output and employment levels.

The demand for timber in the Flathead and elsewhere has traditionally been linked to the health of the national economy. In recent years, high interest rates have discouraged businesses and individuals from taking loans to finance new construction. The housing industry has been especially hard hit, as prospective homeowners have balked at committing themselves to new home payments sometimes equalling 50% or more of their income.

The effect of this cycle on wood products employment was brought sharply into focus during 1980, when record consumer and government debt was coupled with a shortage in the available money supply. The resulting competition for loan capital saw interest and mortgage rates skyrocket, the housing market collapse, and timber employment fall by more than 20% statewide.

Economic events during 1982 and early 1983 displayed some positive signs for the timber industry. Inflation has declined significantly and mortgage rates, while still high, have stabilized. Many economists believe that a declining inflation rate will eventually bring mortgage rates down, although not to the single-digit levels once common.

The North Central states, which constitute the major market for Flathead Basin timber, provide an additional buffer to recessionary impacts on the local wood products industry, as this agricultural region has

TABLE 3.7

Timber Volume Assumptions Flathead and Lake Counties (Average Volume 1980-2000)

	1970-74 Five Year Average		1975-79 Five Year Average		HIGH* (RPA High)		MEDIUM* (RPA Average)		LOW* (RPA Low)	
	MMBF	Percent	MMBF	Percent	MMBF	Percent	MMBF	Percent	MMPF	Percent
Forest Service	140	47%	113	44%	120	46%	110	50%	98	54%
Bureau of Indian Affairs	60	20%	39	15%	46	18%	30	14%	26	14%
State of Montana	14	5%	9	4%	14	5%	12	5%	8	5%
Private	84	28%	99	38%	80	31%	69	31%	50	27%
	298	100%	260	100%	260	100%	221	100%	182	100%

Sources: Tables 3.4 and 3.5

Medium Assumptions
Federal: 110 Average of RPA high and low
Indian: 25% Reduction on Indian land
State: 33% Increase in State lands
Private: 30% reduction on private lands

Productivity	(Volume per man)
1979	89,117
1990	84,943
2000	72,958

*Note: The Forest Service no longer utilizes a range for RPA projections. Congress recently adopted the high figure as the official planning target. However, at the time of the present analysis a range of targets was still used.

proven to be less effected by national business cycles. The age structure of the American population also bolsters the timber demand outlook, with a large number of persons born in the 1950s poised to enter the housing market when economic conditions improve.

Collectively, these factors suggest that demand for Flathead Basin timber will gradually rebound, but will still remain below levels of the 1970s. The best numerical forecast indicates that the annual volume of timber harvested during the next two decades will be 15% lower than the average cut during the 1975-79 period (Table 3.7). The future may also see a greater reliance on national forests to meet timber demands, because recent heavy harvest rates on private lands probably cannot be sustained.

Surprisingly, a reduction in the timber cut is not expected to signal a decrease in overall employment in the Flathead Basin wood products industry. More efficient mills and increased utilization of wood residue in plywood and particle board production have steadily increased the number of jobs per volume of wood harvested. A continuation of this trend is expected, and the result should be the addition of about 23 new jobs annually in Flathead and Lake counties. Summed over the next two decades, the regional wood products industry is projected to support a total of 467 new basic jobs by the year 2000.

The future of the metal refining industry in the Flathead Basin depends primarily on two factors—the demand for aluminum and the cost of the large amounts of electricity needed for production. Industry analysts predict an ever-growing demand for this light-weight metal, which is used increasingly in the production of automobiles and energy transmission lines. According to U.S. Department of Interior projections, domestic aluminum needs will triple by the end of the century (Table 3.8). On the cost side of the ledger, recent legislation by the U.S. Congress has guaranteed that electricity rates charged to aluminum producers will rise dramatically from their previously very low levels.

This combination of factors means that aluminum production at the Anaconda plant in Columbia Falls should remain profitable, but the increased costs of electricity make further expansion unlikely. Overall employment levels are thus projected to remain constant; any changes will be short-term, such as the recent layoffs in response to the recessionary national economy and the anticipated temporary increase in plant employment with the planned construction of a new facility for casting aluminum ingots.

TABLE 3.8

Comparison of Domestic Aluminum Demand, 1957-77, and Projected Demand In 1985 and 2000

(Thousand short tons)

Year	U.S. Primary Demand
1957	1,822
1958	1,737
1959	2,101
1960	2,060
1961	2,079
1962	2,369
1963	2,702
1964	2,888
1965	3,275
1966	3,903
1967	3,756
1968	4,194
1969	4,328
1970	4,071
1971	4,576
1972	5,290
1973	6,284
1974	5,897
1975	4,160
1976	5,348
1977	5,581
1985	9,850
2000	18,000

Source: Department of Interior, Aluminum Outlook, 1977.

Stability of the primary metals industry marks a significant change from the last decade, when this basic sector was responsible for almost half of total employment and population growth in the region. The absence of an economic growth stimulus from aluminum refining severely dampens prospects for continuing the recent high growth rate of the local economy. At the same time, this industry will remain the second largest income producer for workers in the region.

While the Flathead Basin offers a steady "supply" of tourist attractions, headed by Glacier National Park and Flathead Lake, the demand for recreational travel can fluctuate greatly on an annual basis. During the 10-year period ending in 1978, an increasing American population with ample leisure time fed a growing tourist industry in the Flathead Basin. In 1979, however, gasoline prices rose by 50%, and the number of tourists visiting northwestern Montana dropped by 17% (Fig. 3.3). Between 1960 and 1980, almost all of the annual variation in visitor numbers at Glacier National Park was attributable to changes in both the price of gasoline and the number of American households.

An economic forecast, incorporating gas at $4 a gallon along with a 22% rise in the number of U.S. households by 1990, projects future expansion of the tourist industry in the Flathead Basin. The scale of this expansion is expected to be less than half as great as the growth from 1968-1978, when tourist dollars created over 125 new basic jobs each year (Table 3.9). Economists caution that unanticipated changes in fuel availability may curtail long-distance automobile travel and thus set back growth projections for the tourism industry.

Transportation by means other than automobiles also influences regional tourism prospects. Continuation of passenger train service by AMTRAK, which

TABLE 3.9

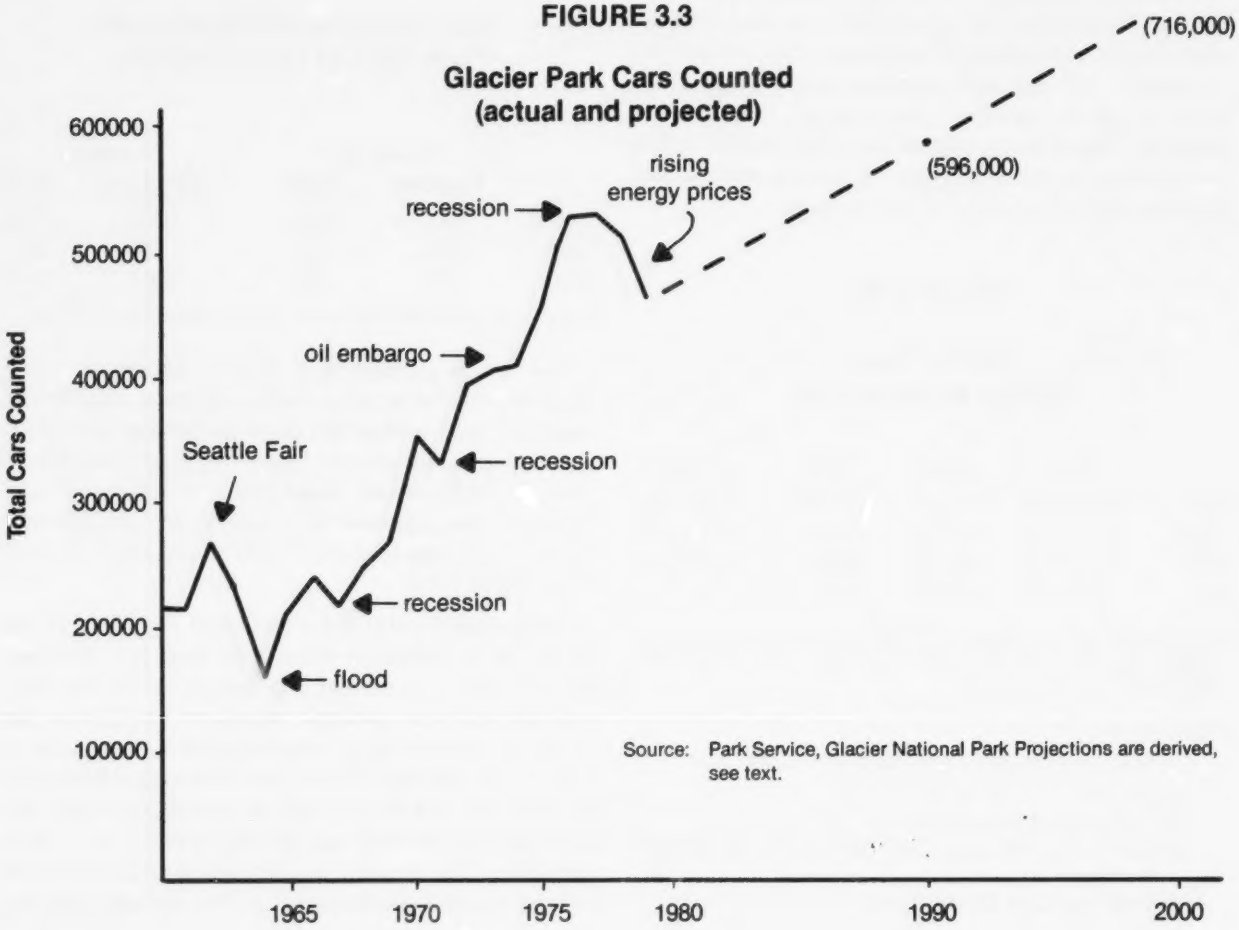
Travel and Tourism Employment Projections (Flathead and Lake Counties)

	(Trend) High	Medium	Low
1980	2158	2158	2158
1990	3529	2823	2542
2000	4759	3426	2923
increase 1980-2000	2601	1326	765

Assumptions:
High: Long-term trend (1967-79)
Medium: See narrative
Low: Without increase in stay

Source: Derived

FIGURE 3.3



Glacier Park Cars Counted (actual and projected)

Source: Park Service, Glacier National Park Projections are derived, see text.

annually brings 10,000 skiers to Whitefish and the Big Mountain resort, is essential to the fledgling winter tourism industry. In light of recent federal budget-cutting, however, AMTRAK's future is far from assured. Group tours by bus have been the fastest growing sector of the regional tourism industry. Bus travel is projected to more than double in popularity by the year 2000, although bus passengers will still constitute only 4% of Flathead Basin tourist trade (Table 3.10).

Studies of regional travel patterns indicate that Montana should be capturing a greater share of the tourist trade from the northwestern United States and Canada. Travel promotion directed at these nearby, underexploited markets could significantly increase tourism in the Flathead Basin. Emphasis on convention and resort destinations holds promise for drawing a greater number of relatively affluent travelers to northwestern Montana. This segment of the tourist population is less affected by high fuel costs and could help offset the effects of the anticipated slow growth in automobile travel.

Economic forecasts for agriculture are notoriously difficult because of the industry's boom-and-bust cycles. Farm and ranch income varies widely in response to supply and demand considerations, government price supports, weather, and a range of other influences. These uncertainties notwithstanding, a few well-defined trends will likely control the agricultural industry through the end of the century.

TABLE 3.10

Visitor Days
Glacier National Park

	Car	Bus	Train	Total
1970	1,241,603	15,516	2,074*	1,259,193
1980	1,475,538	35,797	2,493**	1,513,828
1990	1,698,600	56,078	3,905	1,758,583
2000	1,969,055	76,359	5,317	2,050,731

* Assumes same as 1980 proportions ** 1979 boardings at Glacier

Assumptions:

1) 2.85 persons per car in 1990 and 2.75 in 2000
2) Amtrack is continued
3) 3.36 days average stay
4) Bus traffic increase (1980-2000) same as 1970-80 increase
5) Train increase similar to bus

The recent decline of agricultural employment in the Flathead Basin parallels a statewide shift toward fewer and larger farms with a reduced labor force. This shift has been made possible by the use of machinery and chemicals to accomplish tasks formerly done by workers. As a result, energy consumption in agriculture has increased nearly eight times as fast as the rise in food energy produced.

During the next two decades, dependence on petroleum based fuels for energy will continue to dim the prospects for agricultural employment in the Flathead Basin. As rising fuel prices boost the costs of production and transportation, more farm expenditures will be energy-related and less will go to workers' salaries. Subdivision will keep eroding the local agricultural land base and eliminate associated employment opportunities. Also, abandonment of rail transportation may cost agricultural jobs by making some farms and ranches uneconomical to operate.

TABLE 3.11

Total Agricultural Employment
Flathead and Lake Counties

	Flathead		Lake	
	Forecast	Trend	Forecast	Trend
1978	976	976	1286	1286
1990	854	749	1197	1295
2000	771	552	1123	1245

Source: Montana Department of Administration, MASS II Model.

The forces prompting a decline in employment, however, should be tempered by rising worldwide demand for food, which will boost prices for farm products and maintain a level of profitability in the industry. Overall, agricultural employment in Flathead and Lake counties is projected to drop from the 1978 level of 2,260 workers to about 1,900 workers by the year 2000 (Table 3.11).

Employment gains are anticipated in several of the minor basic industries during the next two decades. Recent interest in oil and gas leasing in the Flathead, and the region's geologic similarity to Alberta gas fields, indicate potential employment opportunities in the energy industry. Geologists are skeptical that a major hydrocarbon source will be found, but many believe limited natural gas development is a distinct possibility. The current analysis assumes 100 new jobs will be created regionwide in the energy industry during the next 20 years. Construction, light manufacturing, retail and wholesale trade, and other business ventures should collectively generate about a thousand new basic jobs, which is over one-third of the expected regional growth in basic employment. No change in the level of government employment is projected.

Economic development opportunities. Many government and civic organizations have recently stepped up efforts to attract new manufacturing firms and other established businesses. Although widely touted as a means to stimulate economic growth, such efforts are unlikely to play a major role in the economic future of the Flathead Basin or elsewhere in Montana. Distance from national markets, high transportation costs, and a shortage of specialized labor are the primary competitive disadvantages for drawing manufacturing firms to the region.

On the other hand, efforts to foster the expansion of existing local basic industries, especially those based on the area's natural resources, do stand a good chance of success. Nearly 75% of manufacturing activities in Montana are directly linked to natural resource development, and timber and agricultural products are available in good supply in the Flathead Basin. Montana enjoys lower than average utility rates, an obvious advantage for industries involved in processing raw materials. Additional development of tourist facilities also offers an opportunity to bring in new wealth and provide more jobs in the region. As demonstrated during the past decade, the growth of existing operations, rather than the entry of out-of-state firms, has created the vast majority of new basic jobs in the region.

Among the likely candidates for successful business expansion in the Flathead Basin over the next two decades are the processing of meat and animal by-products, the production of pulp, cardboard, and building paper, and the manufacturing of furniture. Plywood, grain products, prefabricated buildings, and aluminum castings also show some potential for successful expansion of production capacity and job opportunities.

Summary of employment projections. The combined projections for the basic industries indicate a positive future for the Flathead Basin, although the rate of economic growth will be considerably slower than during the 1970s. Wood products and tourism will provide the main impetus for business expansion and new jobs over the next two decades. Primary metals, which comprised the largest share of recent employment and income growth, will maintain a stable level of employment, contributing only a minor amount to economic growth through wage increases. Continued loss of jobs will characterize agriculture, but the rate of job loss will slow somewhat. Despite declining employment, agriculture will remain an integral component of the Flathead Basin economy. A number of minor basic industries, including energy development, construction, manufacturing and small independent businesses, are projected to exhibit sustained growth during the next two decades. The rising importance of these industries will contribute to the diversification of the Flathead Basin economy.

In numerical terms, the region should realize about 12,000 new jobs by the year 2000. One-fourth of these jobs will open up in the basic sectors, while the remainder will comprise the non-basic employment response to new earnings generated by the basic industries. Overall, employment will grow at about one-third of the very rapid rate characterizing the 1970s.

Population projections. Population projections mirror the anticipated employment increases in the Flathead Basin, with steady growth occurring but at a rate about one-third of that which characterized the 1970s boom period (Table 3.12 and 3.13). About 60% of the basin's population growth will come through natural increase, as births are expected to exceed deaths by 9,200 persons during the next two decades. In-migration will constitute the remainder of the population increase, with 6,000 people expected to come to the basin in response to new job opportunities. The population of the Flathead Basin under the moderate (most likely) economic growth scenario is thus projected to be 88,600 residents in the year 2000, a 22% increase over the 1980 census totals. Projections based on high and low levels of future economic performance display likely limits of countywide populations (Fig. 3.4 and Fig. 3.5).

The expected population distribution reflects a continuation of recent trends toward rural living (Table 3.14). Although the five largest cities should all increase in absolute population size, the proportion of residents living in these cities will remain stable or decline slightly. Rural areas, on the other hand, will experience relative gains in population. In the year 2000, Kalispell's municipal population is projected to be slightly under 11,000, while Whitefish, Polson, and Columbia Falls will all have between 3,000 and 4,000 residents.

TABLE 3.12

Medium Scenario (Flathead)

	1970	1980	Annual Growth Rate 1970-80	1990	2000	Annual Growth Rate 1980-2000	Percent of 1970-80 Growth Rate
Basic Employment	6,692	(1979)* 8,460	2.64%	9,567	10,775	1.16%	44%
Total Employment	14,453	(1979)* 21,893	4.72%	26,573	31,478	1.74%	37%
Population	39,460	51,966	2.79%	57,128	62,451	.92%	33%
Natural Growth Population Level**	n/a	51,966	n/a	56,427	59,024	n/a	n/a
Migration**	n/a	(1970-80) 9,400	n/a	(1980-90) 701	(1980-2000) 3,427	n/a	n/a

* 1979: Employment estimates by Montana Department of Administration

** Note: Population level based on expected births and deaths; Series II—U.S. Bureau of the Census. Migration levels are estimated from state vital rates.

Sources: Research and Statistical Services Bureau, Montana Department of Administration, MASS II Model; U.S. Bureau of the Census, 1980 Census of Population, Vol. 1, *Characteristics of the Population*, Chapter A, Number of Inhabitants Montana, October 1981.

TABLE 3.13

Medium Scenario (Lake)

Category	1970	1980	Annual Growth Rate 1970-80	1990	2000	Annual Growth Rate 1980-2000	Percent of 1970-80 Growth Rate
Basic Employment	2,186	(1979)* 2,590	1.9%	2,914	3,165	1.0%	53%
Total Employment	4,450	(1979)* 6,388	4.1%	7,737	8,842	1.6%	39%
Population	14,445	19,056	3.1%	21,853	23,761	1.1%	35%
Natural Growth Population Level**	n/a	19,056	n/a	20,301	21,161	n/a	n/a
Migration**	n/a	(1970-80) 3,400	n/a	(1980-90) 1,552	(1980-2000) 2,600	n/a	n/a

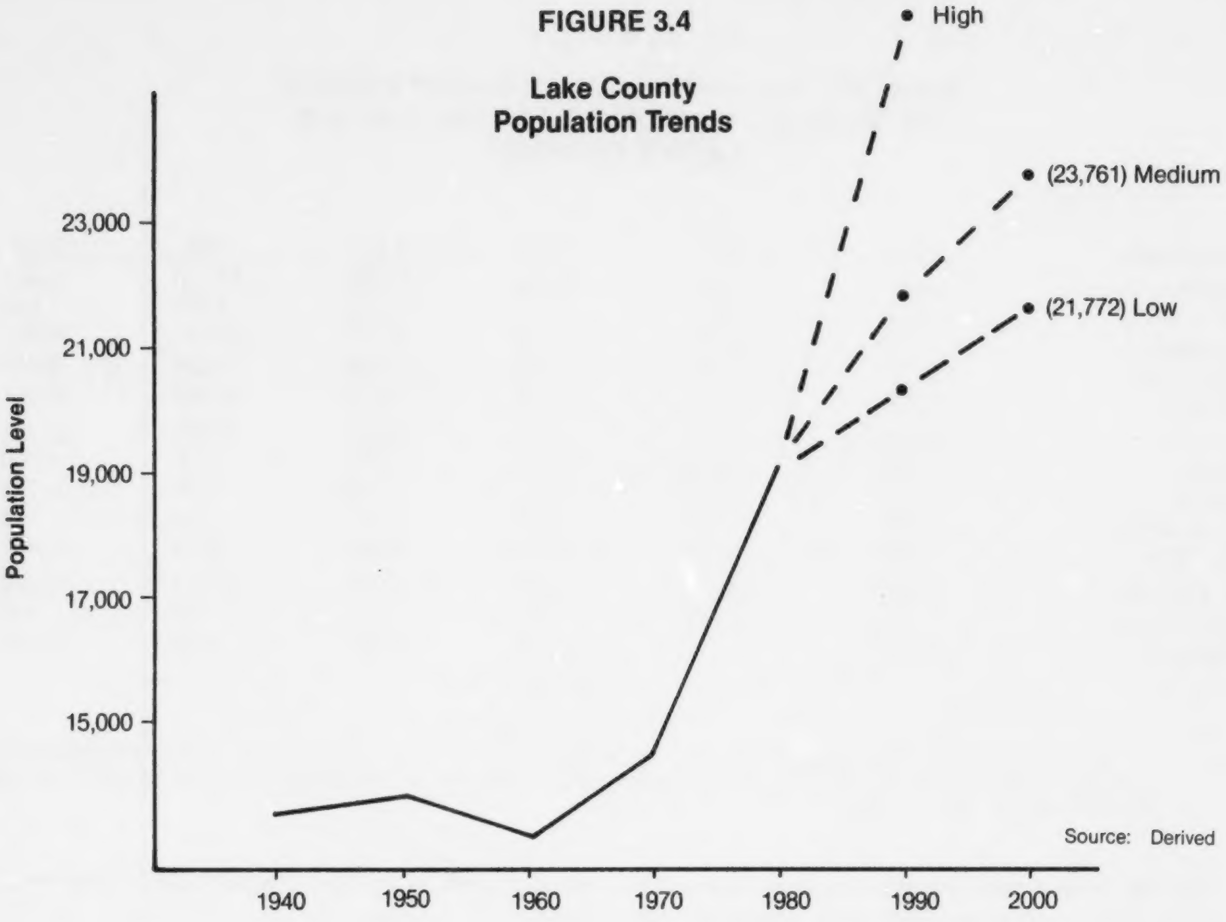
* 1979: Employment estimates by Montana Department of Administration

** Note: Population level based on expected births and deaths; Series II—U.S. Bureau of the Census. Migration levels are estimated from state vital rates.

Sources: Research and Statistical Services Bureau, Montana Department of Administration, MASS II Model; U.S. Bureau of the Census, 1980 Census of Population, Vol. 1, *Characteristics of the Population*, Chapter A, Number of Inhabitants Montana, October 1981.

FIGURE 3.4

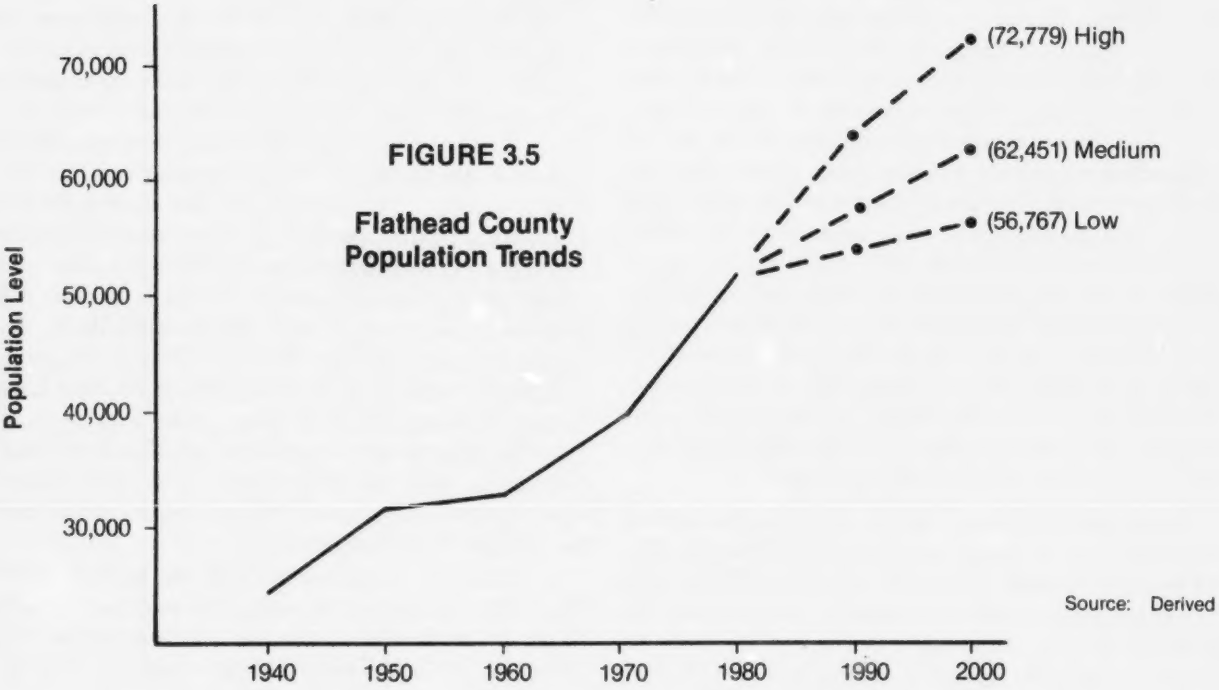
Lake County Population Trends



Source: Derived

FIGURE 3.5

Flathead County Population Trends



Source: Derived

TABLE 3.14

Actual and Projected Population (Medium Scenario) For Selected Communities in Flathead, Lake and Sanders Counties.

Jurisdiction	1950	1960	1970	1980	1990	2000
Flathead Co.	31,495	32,965	39,460	51,966	57,128	62,451
Col. Falls	1,232	2,132	2,652	3,112	3,450	3,690
Kalispell	9,737	10,151	10,526	10,648	10,770	10,850
Whitefish	3,268	2,965	3,349	3,695	3,880	3,970
Residual	17,258	17,717	22,933	34,511	39,028	43,941
Lake Co.	13,835	13,104	14,445	19,046	21,853	23,761
Polson	2,280	2,314	2,464	2,798	3,130	3,500
Ronan	1,251	1,334	1,347	1,530	1,640	1,770
St. Ignatius	781	940	925	877	830	800
Residual	9,523	8,516	9,709	13,851	16,253	17,691
Sanders Co.	6,983	6,880	7,093	8,675	10,444	12,328
Hot Springs	733	585	664	601	590	595
Residual	6,250	6,295	6,429	8,074	9,854	11,733

Source: U.S. Bureau of the Census, 1980 Census of Population, Vol. 1, *Characteristics of the Population*, Chapter A, Number of Inhabitants, Montana, October 1981; U.S. Bureau of the Census, Census of Population, 1950, Vol. II, *Characteristics of the Population*, Part 26, Montana, 1952; projections derived.

Fiscal projections. Municipal governments in the Flathead Basin are expected to have increasing difficulty funding necessary services and capital improvements. This pessimistic fiscal outlook, projected through 1990, results from a number of trends that characterize most of the region's local governments. First, operating expenses will continue to rise, as the expanding population requires more services and inflation escalates the costs of salaries and benefits, road and utility maintenance, and interest on borrowed money. Secondly, a continued tightening of federal revenue sharing and grant programs can be anticipated, reducing the contribution of these two important funding sources. Finally, the real (adjusted for inflation) taxable value of properties in the Flathead Basin is expected to keep falling, as residential, commercial, and industrial structures lose value faster than new construction increases the tax base.

Taken together, these trends mean an increasing need for local revenues in the face of a declining ability to generate them. Cities and counties will thus have to extract more revenue relative to taxable property value to remain financially solvent. For the average taxpayer, these budgetary pressures will mean a dramatic increase in the costs of supporting local government.

The fiscal "burden" placed on taxpayers can be computed by comparing government operating expenses to taxable property value. High government costs, coupled with a low tax base, impose a high burden, as residents must generate more revenue relative to their property value. Low government costs and a high property tax base result in a low burden for the average taxpayer. Currently, fiscal burden is relatively low in the two counties and moderate in the cities and towns. During the next decade, however, burden will increase in all jurisdictions in the Flathead Basin, rising by just over 40% in Flathead County, Kalispell, and Hot Springs, and increasing 96% to 140% in Lake County, Columbia Falls, Polson, Ronan, and St. Ignatius. The counties will continue to exhibit a lesser burden than the municipalities, and the larger municipalities will generally show a lesser burden than the smaller towns (Table 3.15).

In Whitefish, fiscal burden will rise by only 10%. Whitefish is projected to escape the regionwide trend of declining taxable value, as new residential and commercial development should continue. This in-

TABLE 3.15

Projected Changes in Fiscal Reliance, Real Operating Expenditures Per Capita ($ 1980), 1980-1990.

	Local Fiscal Reliance	Local Fiscal Burden	OPEXP/Capita
Flathead	−19%	+ 41%	+ 7%
Lake	− 9%	+100%	+16%
Kalispell	− 1%	+ 42%	+ 9%
Whitefish	− 2%	+ 10%	+17%
Columbia Falls	−24%	+ 96%	+20%
Polson	−17%	+125%	+27%
Ronan	−18%	+105%	+38%
St. Ignatius	−17%	+140%	+35%
Hot Springs	+30%	+ 43%	−14%

Source: Western Analysis, Inc., Helena, Montana.

creasing tax base gives Whitefish the capacity to meet rising financial needs without significantly increasing the burden on municipal taxpayers.

Major capital expenditures will be required to maintain an adequate level of government services for the expanded regional population. Public safety and water systems have been identified as the most pressing local needs. Funding capital improvements, however, will exacerbate the anticipated financial problems of local governments in the Flathead Basin. Flathead County (with a proposed new courthouse and jail complex), along with Whitefish, Columbia Falls, and Ronan (each with plans to upgrade water and sewage treatment systems) would suffer the greatest relative impact on municipal budgets if these construction projects are undertaken.

The fiscal projections indicate that local governments in the Flathead Basin will need additional funding sources to balance budgets and prevent excessive tax burdens during the coming decade (Table 3.16). A combination of reduced services and elevated property tax rates, fees, licenses, and utility charges can be anticipated. City and county governments may also request more money from the State, along with new authority to raise local revenues, such as the hotel "bed tax" approved by Billings voters in 1982. Finally, municipalities are likely to seek revenue from county residents who use, but do not pay for, city services. Annexation is commonly seen as a potential method to spread city government costs among all urban and suburban residents. Resistance to annexation and the associated higher tax rates, however, is strong among many residents of unincorporated areas. Because state law allows the affected voters to reject annexation, this procedure remains a political uncertainty for securing increased funding for municipal governments.

Although population increases and the accompanying demands for services may contribute to the fiscal problems in the Flathead Basin, the projected economic shortfalls are common to local governments throughout Montana declining real taxable values, shrinking federal revenue sharing and grant programs, and increasing costs of government operations together foreshadow a difficult future for local governments.

TABLE 3.16

Projections of Selected Local Government Finance Data, Percentage Change ($ 1980), 1980-1990.

Tax Jurisdiction	Taxable Value	Local Revenues*	Operating Expenditures*
Flathead			
1980-1985	− 7	−10	3
1980-1990	−15	− 4	18
Lake			
1980-1985	−19	9	9
1980-1990	−35	21	33
Kalispell			
1980-1985	− 9	8	4
1980-1990	−20	13	14
Whitefish			
1980-1985	10	13	15
1980-1990	17	23	26
Columbia Falls			
1980-1985	−17	−11	17
1980-1990	−32	0.2	33
Polson			
1980-1985	−21	7	18
1980-1990	−37	16	40
Ronan			
1980-1985	−15	10	14
1980-1990	−20	22	48
St. Ignatius			
1980-1985	−44	3	20
1980-1990	−46	6	28
Hot Springs			
1980-1985	−28	3	−15
1980-1990	−42	10	−16

*Without planned capital facility expenditures.

Source: Western Analysis, Inc., Helena, Montana.

Economic Values of the Flathead Lake and River System

As part of its regional economic assessment, the Flathead River Basin Environmental Impact Study investigated two primary values of the Flathead Lake and River system: recreation and preservation. Recreation value derives from the thousands of travelers who annually enjoy the fishing, boating, swimming, and camping opportunities associated with Flathead waters. Preservation value reflects the benefits the public receives from having water quality and environmental integrity maintained in the Flathead system.

Both recreation and preservation values have historically been underestimated in evaluating the economic trade-offs occasioned by resource development. The resulting emphasis on commodity values has often tipped the scales away from environmental protection. Recently, however, water resource specialists developed a reliable and impartial way to measure recreation and preservation values. This state-of-the-art method, based on the public's willingness to pay, was applied to determine the recreation and preservation values of the Flathead Lake and River system.

Recreation value. As a first step in determining the recreational value of the Flathead Lake and River system, the Montana Department of Fish, Wildlife and Parks conducted an extensive survey of recreational use and tourist travel costs. The survey, which continued for a year from its May 1981 beginning, encompassed Flathead Lake, the upper Flathead River, the Middle Fork (fall kokanee-snagging season only), and the North Fork (U.S. portion only). Each recreationist who participated in fishing, boating, swimming, or camping for any length of time was assigned a visitor-day in that category; for individuals who took part in more than one activity in a day, a single visitor-day was apportioned among the appropriate recreational categories. Boat and car counts were statistically referenced to personal interview results so a valid estimate of total recreational use could be derived.

Recreation on Flathead Lake, Montana Travel Promotion Bureau

The recreational survey determined annual use of 680,000 visitor-days on Flathead Lake and an additional 60,000 visitor-days on the rivers. Fishing was the dominant activity, constituting 36% of recreational use on Flathead Lake during the summer (mid-May through Labor Day) and 89% during the non-summer period, when swimming, camping, and recreational boating dropped off sharply. On the rivers, fishing made up 90% of total recreation during the seasons surveyed (Table 3.17).

Researchers determined the value of this tremendous amount of recreational activity by treating each trip as a market transaction, with a buyer (the traveler), a product (the recreational activity), and a price (the money spent to gain access to Flathead waters). The total travel costs incurred by all travelers provides a direct value for recreation in the Flathead Lake and River system, much as admission receipts indicate the economic value of a movie or sporting event.

Significantly, the travel costs which determine recreation value include only vehicle operating expenses. This approach is designed to yield the value of the Flathead drainage **to the user** by showing how much users are willing to pay specifically for access to water-based recreation. Recreation value purposedly does not include the economic value to the regional tourism industry. This latter value would take into account money spent for accommodations, meals, fishing tackle, groceries, and related items. Although this regional economic impact is many times greater than the narrowly defined recreation value, water resource analysts reject this as a measure of recreation value because it encompasses many values not directly related to recreation. The travel-cost approach also neglects the enhanced value of lakeshore and riverfront properties attributable to their recreational opportunities. In sum, the technique used to value recreation in the Flathead system yields a very conservative estimate, but one which requires few assumptions and can readily be compared to other water resource studies.

Based on survey results, recreationists spent over $5 million to reach and return home from Flathead waters during the year-long survey period (Table 3.18). By properly interpreting these travel costs as a measure of willingness to pay for recreational use, the annual recreation value of the Flathead Lake and River system can be said to exceed $5 million.

Boaters spent $11.53 per day on travel costs, or about twice as much money per visitor-day as participants in other recreational activities. This high daily cost, which indicates that boaters were willing to travel about twice as far as other recreationists to enjoy their sport, made boaters responsible for the largest share of the economic valuation of Flathead recreation. Anglers, with an average travel cost of only $4.91 per trip, were the second largest contributors to the Flathead's recreation value by virtue of their superior numbers.

About 60% of the visitors to Flathead Lake came from Lake County and Flathead counties, while Missoula, Sanders, and Mineral county residents made up a combined 15% of lake recreationists. Overall, Montanans accounted for 84% of the recreational use. Other states contributed 13% of Flathead Lake users, and Canadians constituted 3%. In general, the rate of visits from each place of origin decreased as the distance from the Flathead increased.

For most of the recreationists interviewed, visiting Flathead Lake was the sole or primary purpose of their trip. Trips to the lake averaged less than two days in duration.

Preservation value. Many persons are interested in preserving the Flathead Lake and River system for reasons which transcend immediate recreation value.

TABLE 3.17

Recreation Participation of Flathead Lake by Activity for 1981

Activity		Summer	Non-Summer	Total
Fishing		218,442	71,002	289,444
Swimming		140,634	48	140,682
Camping		53,473	2,094	55,567
Boating		187,567	6,742	194,309
	Total	600,116	79,886	680,002

TABLE 3.18

Recreation Demand and Value Estimates for Flathead River and Lake

Activity	Visitor Days	Value Per Trip	Total Value
Flathead Lake			
Swimming	140,682	$ 4.81	$ 676,680
Boating	194,309	11.53	2,240,383
Fishing	289,444	4.91	1,421,170
Camping	55,567	5.92	328,957
	680,002		$4,667,190
Flathead River			
Fishing* (N.F.)	9,485	$ 5.94	$ 56,341
Fishing (M.F.)	8,040	5.92	47,597
Fishing (M.S.)	35,940	5.93	213,124
Boating (North and Middle Forks)	6,221	11.23	69,861
	59,686		386,924
Grand Total	739,688		$5,054,114

*The abbreviations N.F., M.F., and M.S. refer to the North Fork, Middle Fork and Mainstem of the Flathead River respectively. The North Fork estimate reflects the summer period only. The Middle Fork estimate represents the September 12 through November 30 period, which is the Kokanee snagging period.

Those who do not currently use Flathead waters may wish to maintain the **option** of being able to enjoy the recreational opportunities in the future. Others would like to have the Flathead system conserved as a **bequest** to future generations. A third non-use category of value is the satisfaction people gain simply from knowing of the **existence** of this unique resource, apart from any expectation of future use.

Option, bequest, and existence values are collectively termed the "preservation value"—that is, the benefit which the public derives from having the Flathead Lake and River system preserved. Although this benefit is psychological rather than monetary, water resource specialists have quantified preservation value by defining it as the money the public would be willing to pay to preserve environmental values.

To determine the preservation value of water quality in the Flathead system, questionnaires were mailed to a random sample of households in Kalispell, Missoula, Butte, and Billings. Recipients were asked to write down "the maximum amount of money [their] household would be willing to pay annually to protect water quality" in the Flathead Lake and River system. Recipients were also asked to apportion this total figure by percentage into each of four categories: payment for recreation in the current year, the option for future recreational use, the personal value of being able to pass good water quality on to future generations, and the satisfaction derived from the existence of good water quality in the Flathead system. The combined monetary value assigned to the latter three categories (option, bequest, and existence) equals the preservation value of Flathead water quality.

The preservation value, or annual willingness to pay to preserve water quality, averaged about $57 per household, based on 171 questionnaire responses (Table 3.19). Bequest value equaled $26.37 of this total and ranked as the highest component of preservation value. The existence value of a clean Flathead Lake and River system averaged $19.88 per household, and the option for future use was valued at $10.71. Willingness to pay for access to Flathead water in the current

TABLE 3.19

Frequency distribution and mean value of expected consumer surplus from recreation use, option, existence and bequest value of water quality, Flathead Lake and River, Montana, 1981.

	Number of Respondents				
Value Categories	Option Value	Existence Value	Bequest Value	Recreation Use Value	Total Value
Zero	90	80	78	101	73
$ 0.01 — 1.99	11	11	20	11	1
2.00 — 9.99	32	41	27	31	24
10.00 — 24.99	21	34	28	20	16
25.00 — 49.99	8	9	12	4	14
50.00 — 99.99	6	6	9	2	24
100.00 — 199.99	2	1	3	1	7
200.00 — 299.99	1	2	0	1	5
300.00 — 499.99	0	1	4	0	2
500.00 — 999.99	0	1	1	0	3
1,000.00 and above	0	0	0	0	2
Mean Values	$10.71	$19.88	$26.37	$7.37	$64.16

year averaged only $7.37, about one-eighth of the combined preservation value, indicating that respondents considered long-term preservation far more valuable than one-time recreational use. The average values in all categories included 77 respondents (45%) who indicated that they would pay no money to preserve water quality in the Flathead system.

Survey results indicated that the closer a household was to the Flathead, the more likely members had visited the area. As might be expected, this greater visitation rate translated into the higher preservation value reported by nearby households. Statistically, the value of preserving water quality in the Flathead drainage averaged just over $73 for respondents from Kalispell (10 miles from Flathead Lake) and dropped off about 11¢ for each additional mile the household was located from Flathead Lake.

This observed relationship between preservation value and distance was applied to all households within the seven-state, three-province region surrounding the Flathead Basin. The resulting calculations indicated the public would be willing to pay over $97 million annually to preserve water quality and related values in the Flathead system (Table 3.20).

The $97 million preservation value was obtained within a 650-mile radius of Flathead Lake; beyond this limit, the calculated willingness to pay, based on distance, was zero for all households. These calculations reflect the recreational survey findings, which indicate that the Flathead system draws from a regional tourist clientele, rather than a national one.

Residents of Washington were estimated to value preservation of the Flathead Lake and River system at $46 million annually, and residents of Alberta were determined to have a $19 million annual interest in Flathead drainage water quality. These values, which exceed the $13 million figure for Montanans, reflect the large population centers (Spokane, Seattle, Calgary, and Edmonton) which lie within the 650-mile radius of the Flathead.

Because preservation value questionnaires were sent to Montanans only, the relationship between distance from the Flathead and willingness to pay for preservation may not be strictly applicable to households in other political jurisdictions. The typical resident of Seattle, for example, may not place as high a value on preserving the Flathead system as the typical Billings resident, who lives a similar distance away. If

TABLE 3.20

Aggregate annual preservation values for Flathead Lake and River, Montana, 1980.

States and Provinces	Mean Distance	Preservation Values ($1,000)			
		Option	Existence	Bequest	Total
Montana	184	$ 2,671	$ 4,737	$ 6,166	$13,574
Washington	416	11,020	15,268	19,816	46,104
Oregon	735	2,511	0	0	2,511
Idaho	611	1,404	544	527	2,475
North Dakota	845	213	0	0	213
South Dakota	971	0	0	0	0
Wyoming	712	476	0	0	476
Total, States		$18,295	$20,549	$26,509	$65,353
British Columbia	558	$ 4,192	$ 3,211	$ 3,850	$11,253
Alberta	403	4,501	6,412	8,345	19,258
Saskatchewan	637	1,214	178	39	1,431
Total, Provinces		$ 9,907	$ 9,801	$12,234	$31,942
Grand Total		$28,202	$30,350	$38,740	$97,295

out-of-state residents do not value Flathead waters through the same preservation value-distance relationship demonstrated by Montanans, the regional estimate may somewhat overstate the public value of preserving the Flathead system.

On the other hand, many persons living more than 650 miles from Flathead Lake may place a value on preserving this unique resource. The valuation based on travel distance assumed no willingness to pay by persons outside the region, and thus may have considerably underestimated preservation value. The assessment of preservation economics also disregards the values of existing water uses and natural ecological processes. These values depend on good water quality and, although difficult to quantify, significantly increase the public benefit of preserving the Flathead Lake and River system.

Summary. The combined preservation and recreation values of the Flathead Lake and River system are estimated to equal about $102 million annually. Recreation value, directly expressed through the travel costs incurred by visitors, equals $5 million. This does not include many recreation-related economic benefits, such as the heightened value of lakeshore property or the positive impact of tourist dollars to the local economy. The recreation valuation for the Flathead system is based on state-of-the-art methods, and provides an objective measure which can be compared to other water resources nationwide.

Preservation value greatly exceeds recreational use value for the Flathead system. The public would be willing to pay an estimated $97 million annually to protect water quality values; conversely, the public would suffer a $97 million loss if Flathead waters were degraded beyond acceptable water quality standards.

CHAPTER IV
FLATHEAD BASIN AIRSHED

University of Montana Archives, M. J. Elrod Collection, Flathead River below Lake

Montana Travel Promotion Bureau

Although often ignored in a tally of natural resources, clean air is a vital economic and environmental asset in the Flathead Basin. Forestry and agriculture depend on clean air to insure productive growing conditions for trees and crops. Clean air is an essential part of the expanding tourism industry, as many urban dwellers return year after year to enjoy scenic vistas highlighted by the clear skies. Clean air also enhances the quality of life in the region by sustaining good health and contributing to residents' appreciation of their surroundings.

Low population density, a relative scarcity of industrial activity, and an expansive buffer of undeveloped land all contribute to the generally good air quality in the Flathead. But despite these favorable conditions, the basin has proven susceptible to air quality problems. Widespread haze from summer forest fires or fall slash burning periodically obscures scenic vistas, while dust clouds the air near heavily traveled unpaved roads. During winter, temperature inversions sometimes trap air emissions in the populated valley locations. The topography of the region, with a series of mountain ranges ringing a central basin, accentuates the impacts of human activities by hampering the dispersal of pollutants.

The prospect of additional air pollution sources in the Flathead Basin underscores the fragile nature of the regional air quality. The increasing population is the most likely cause of greater pollution levels, as motor vehicle exhaust, road dust, and residential wood smoke can be expected to track population growth.

Natural resource development may also contribute additional air pollution to the region. Open-pit coal mining, as proposed along Cabin Creek on the North Fork of the Flathead River, would liberate large amounts of "fugitive" dust from earth-moving operations, transportation, and spoils piles, in addition to sulfur emissions from an on-site coal drying plant. Development of underground gas reserves represents another possible source of air pollutants, because the "sweetening" plants often needed to remove impurities emit sulfur-containing gases.

These existing problems and anticipated future pressures underscore the fragile nature of clean air in the Flathead Basin. To gain a better understanding of the regional air resource and how to protect it, the Flathead River Basin Environmental Impact Study sponsored an intensive program of air quality research. The five-year effort began in 1978 and was conducted by the Air Quality Bureau of the Montana Department of Health and Environmental Sciences.

The objectives of the air quality research were:

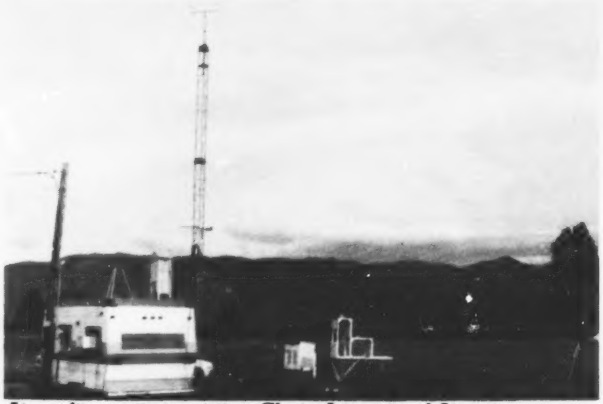
to measure existing air quality within the Flathead Basin,

to identify the levels and sources of air pollution,

to determine how local weather patterns affect air quality,

to assess the impacts of future development on regional air quality, and

to develop guidelines to protect and enhance the air quality of the basin.



Air quality monitoring station, Glacier International Airport

In analyzing air quality influences, researchers viewed the Flathead as a discrete air quality region, or "airshed", with very clean background air subjected to a variety of pollution and meteorological influences within the confines of the basin. The airshed approach allowed scientists to pinpoint problems, to predict impacts of new pollution sources, and to offer recommendations for maintaining regional air quality. A comprehensive basin-wide assessment of how the Flathead Basin airshed functions thus forms the cornerstone of the Flathead River Basin Environmental Impact Study air quality research.

History of Air Quality Concern

Early articles extolling the virtues of the Flathead Basin referred to the region's clear, scenic vistas and excellent air quality. Major W. H. Smead, federal agent for the Flathead Reservation during the early 1900s, wrote, "The pure, dry air makes the most healthful conditions prevail. For persons suffering from asthma, hay fever, and consumption, there are few better places." Wildfires, however, were an important seasonal source of air pollution; forest fires during the summer of 1910 burned three million acres in western Montana and northern Idaho and thick smoke was reported throughout the region.

Following decades saw the growth of population centers, with industrial, vehicular, and residential sources all beginning to affect the pristine air of the basin. The "teepee" burners used to incinerate wood wastes were the most visible symbols of air quality degradation, as plumes of gray smoke accompanied most lumber mills.

During the 1960s, regional attention focused on the Missoula Valley airshed to the south, where smoke and gases from wood products operations and other urban sources were producing pollution levels hazardous to public health. Eye irritation and respiratory difficulties were widespread symptoms among the population, especially during extended stagnant air conditions caused by winter temperature inversions.

The Missoula situation underscored the vulnerability of western Montana's intermountain airsheds to elevated pollution levels. Although most areas in the Flathead Basin still retained good air quality, some residents began to realize that clean air could not be taken for granted.

Concern about smoke pollution and public health consequences prompted a 1964 study of airborne particle concentrations in the upper Flathead River Valley. Based on air quality sampling, the Montana Board of Health concluded that there was "a strong potential for the development of a serious air pollution situation." The study identified smoke and ash from the burning of logging slash, sawmill residue, agricultural stubble, and garbage, along with industrial emissions, as the main sources of particulate pollution in the valley. Reference was also made to low wind speeds and the high frequency of atmospheric temperature inversions as factors which acted to concentrate air pollutants in the Kalispell-Columbia Falls area.

A 1974 study by the Montana Department of Health and Environmental Sciences recalled the warnings of a decade earlier, providing evidences of air pollution injury to residents of western Montana valleys. Statistics compiled from five years of death certificates revealed an abnormally high fatality rate from asthma, emphysema, and bronchitis. These disorders, collectively termed "chronic obstructive pulmonary diseases", indicate long-term blockage of lung function, exactly the kind of respiratory difficulty caused or aggravated by particulate air pollution. Occupational correlations failed to explain the high death rates; rather, the data pointed to an overall environmental problem, such as air pollution.

Health service data from the Flathead Reservation for 1976 through 1978 reinforced indications of a regional population highly susceptible to air pollution impacts. Young children had an exceptionally high incidence of colds, flu, and related infectious upper respiratory diseases, while the overall population rates of asthma and emphysema among tribal members were several times greater than national averages.

View from Big Mountain Ski Area looking at Glacier National Park, Montana Travel Promotion Bureau

During the past several decades of concern over particulate pollution and human health, a great deal of air quality research and public attention was also being directed towards the effects on vegetation of air pollution from the Anaconda Aluminum Company refinery in Columbia Falls. Within two years after the plant opened in 1955, Forest Service officials noticed that nearby conifer trees were dying. Expansion of production capacity during the 1960s increased emissions, and pollution impacts became evident farther downwind. Studies conducted in the early 1970s documented elevated levels of fluoride in trees and shrubs on thousands of forested acres near the plant. Researchers also found potentially dangerous fluoride levels in the bones of deer and small mammals living on Teakettle Mountain, just east of the aluminum plant.

With the benefit of a series of exemptions from state air quality regulations, the Anaconda facility continued to operate and began to make progress in reducing fluoride emissions. In 1978, the company converted to a new refining process and, as a result, fluoride emissions have dropped to approximately 700 pounds per day, or about 90% less than peak levels from a decade earlier. The State of Montana, the National Park Service, and the Anaconda Aluminum Company are continuing to monitor the fluoride content of vegetation in the Columbia Falls area.

Reduced air emissions have also been realized in the burning of logging slash, thanks to a statewide smoke management program established in 1978. A meteorologist from the Montana Air Quality Bureau and a state fire management specialist now make daily determinations from September through November on whether slash burning will be restricted, depending on the ability of the airshed to disperse airborne particulates, the air quality conditions, and the size and location of the proposed burns. The smoke management program coordinated jointly by the Air Quality Bureau and the Forestry Division of the Montana Department of State Lands, enlists the cooperation of state and federal agencies and the major forest landowners in the Flathead Basin.

The 1977 federal Clean Air Act Amendments, which established a nationwide program to prevent air quality deterioration, have provided an important level of protection from industrial pollution to the Flathead Basin airshed. A major section of the amendments specifies how much additional pollution new industrial sources can add to the air. Most of the basin, together with most of the nation, received a Class II designation, which allows moderate pollution increments.

Glacier National Park, the Bob Marshall Wilderness, and the Mission Mountains Wilderness received Class I air quality designation as applied to existing national parks and wilderness areas under the 1977 amendments. These federal lands, termed "mandatory" Class I areas, are provided the most stringent air quality protection under federal law and may not be redesignated to a reduced level of protection. Class I very strictly limits pollution additions from new industries. If specified pollutant increments will apparently be exceeded, a proposed new facility must modify its pollution control design to meet Class I air standards before a construction permit can be issued. Mandatory Class I areas have an additional obligation to protect visibility and other air quality related values, which can include recreation, vegetation, and fish and wildlife populations if these resources are impacted by air pollution. Visibility protection encompasses views within the Class I boundaries and selected outside vistas seen from the Class I area.

Glacier National Park is currently developing a visibility protection program, which includes monitoring of the current visibility conditions and the identification of key scenic viewpoints. The park has also been selected as a research site under the National Atmospheric Deposition Program. This nationwide monitoring network was established to determine geographic trends in the deposition of airborne acidic materials, such as dryfall, acid rain, and acid snow.

In 1982, the Confederated Salish and Kootenai Tribes successfully petitioned the U.S. Environmental Protection Agency to redesignate the Flathead Reservation as a Class I airshed. The Class I designation encompasses all lands within the boundaries of the reservation, including most of Lake County and portions of Sanders, Flathead, and Missoula counties. New pollution sources, whether located on, near, or at a considerable distance from the reservation will be subject to review if the air quality impacts of these developments will extend onto the Flathead Reservation. Sources which will cause pollutant levels to exceed the strict Class I standards will not be permitted to proceed with construction. The tribes pursued the Class I redesignation to preserve health and cultural values on the reservation.

The presence of four Class I areas within the Flathead Basin thus affords substantial protection to the regional airshed (Table 4.1). Federal, state, and tribal officials have legal mandates to insure that major new industrial sources located essentially anywhere in the basin be equipped with advanced pollution control

TABLE 4.1
Class I Airsheds
Flathead River Basin

	Area	% Basin
Bob Marshall Wilderness Area	709,386	12
Confederated Salish and Kootenai Tribal Reservation	89,500	2
Glacier National Park	614,882	11
Mission Mountains Wilderness Area	73,827	1
Total	1 487,645	26

technology to prevent the spread of emissions onto the Class I areas. Such a pollution abatement requirement, in turn, protects air quality in the Class II areas, which comprise the remainder of the basin.

Neither the Class I nor Class II designations, however, guard against the individually minor but collectively important air pollution which can result from the steady growth in residential wood burning, motor vehicle use, and similar population-related sources. This incremental air deterioration represents a potential threat to regional air quality, as evidenced by deteriorating air quality in the more heavily populated Missoula County where wood smoke has in recent years superceded industrial emissions as the focus of public air quality concern.

Class I designation would also provide little remedy for transboundary air pollution, an issue which may surface in the North Fork if coal development proceeds in the Canadian portion of the Flathead drainage.

Air Processes

Air monitoring usually determines to what extent local air differs from pristine air. In most cases, researchers focus on specific compounds, based on a knowledge of pollution sources and the degree of damage posed by the pollutant. Air quality research also includes meteorological investigation, because wind, temperature, and precipitation patterns determine how pollutants will travel in the environment. A review of some general concepts of atmospheric composition, air pollution, and meteorology helps to place in context the air quality research conducted as part of the Flathead River Basin Environmental Impact Study.

Composition of the atmosphere. The earth is enveloped by a 100-mile-thick atmosphere, consisting of gas molecules bound by the planet's gravitational pull. Wind currents, precipitation and other weather forces constantly mix the lower atmosphere and, as a result, the composition of gases remains consistent for about 10 miles above the surface of the earth. Nitrogen and oxygen together constitute 99% of the volume of dry air, while argon and carbon dioxide compose most of the remainder. The concentration of water vapor in the air varies with climatic conditions. During periods of high humidity, gaseous water can be 3% of the air volume. As the water vapor content rises, the relative volumes of the other gases are reduced by a proportional amount.

Among these major constituents of unpolluted air, oxygen and carbon dioxide are the most reactive compounds in biological and chemical processes. Oxygen is the key component in the biological oxidation of food (respiration), which sustains all life, and in the combustion of fuel, which releases the large quantities of energy harnessed for heating, industrial operations, transportation, and other human uses. During combustion and respiration, atoms from oxygen gas combine with carbon atoms from the fuel or food to form carbon dioxide. This oxidation process is essentially reversed during photosynthesis, as plants, using the sun's energy, consume carbon dioxide and produce oxygen gas. Carbon atoms derived from carbon dioxide gas are incorporated into plant tissues during photosynthesis and provide the structural and energy basis for all living matter.

Nitrogen gas, the dominant component of the air, is unreactive in most chemical and biological reactions. Only a few kinds of bacteria and blue-green algae can convert nitrogen into nutrients usable by plant and animals; some of the nitrogen-fixing bacteria are incorporated in the roots of green plants, including alfalfa and clover. Lightning is responsible for about 10% of the conversion of nitrogen gas into usable nitrogen compounds.

Chemists consider argon an inert gas because it does not take part in airborne reactions under normal conditions.

In addition to gas molecules, the air contains a variety of minute liquid and solid compounds, termed particulate matter. Because they are heavier than air, these particles tend to settle back to earth. For particles smaller than about 10 microns in diameter, however, air currents generally override the influence of gravity. These particles can be carried through the air, or "suspended", indefinitely. The amount and kind of particulate matter varies widely, depending on local sources and the effects of weather in circulating, concentrating, or settling out particles. Natural components of the airborne particulate load include volcanic ash and fumes, smoke from wildfires, wind-blown soil, oceanic salt spray, and pollen from vegetation.

Air pollution concepts. Air pollution consists of any deviation from the normal concentrations of compounds in the air which adversely affects human health or welfare, or which is harmful to plants, animals, or exposed objects. In most cases, air pollution is caused by gas or particle emissions from man-made sources; however, pollutants can also be derived from forest and grass fires, volcanoes and other geothermal features, organic decomposition, dust storms, and other natural occurrences.

Air quality terminology differentiates between two kinds of pollution sources. "Point sources" include large, stationary sources of air pollution, such as factories or strip mines. Air pollutants can often be traced to one or more point sources, especially if the pollutants originate from specific industrial sources. The concentration of pollutants from point sources is greatest near the source and decreases as unpolluted air progressively dilutes the pollutant at greater distances. Wind and tall smokestacks help reduce local concentrations but act to carry pollutants and their impacts a much greater distance from the source.

"Area sources" or "nonpoint sources", generally consist of many small, scattered producers of air emissions, such as automobiles, unpaved roads, and residential chimneys. If nonpoint sources are numerous and the air mass is stable, pollutants from these individually minor contributors can accumulate to harmful levels within an airshed.

Airborne chemical reactions among gases, liquid droplets, and solid particles often transform emission products into new compounds and obscure the direct relationship between pollution sources and pollution impacts. Thus, for example, while automobile exhaust contains neither ozone nor formaldehyde, atmospheric reactions involving car emissions are the primary source of these damaging pollutants. Similarly, coal-fired power plants emit little sulfuric acid; however, this principal constituent of acid rain is formed from the sulfur dioxide gas released in power plant stack gases.

Tracking a weather ballon

The interaction of pollutants and weather determines the surrounding, or "ambient", air quality. Generally, if weather conditions cause a significant flow of air, pollutants are dispersed and concentrations decrease. Conversely, if climatic factors prevent air mixing, emissions sources will be adding pollutants to a fixed volume of air. Low-pressure air masses are associated with wind and precipitation and usually serve to reduce concentrations of pollutants by mixing them with large quantities of air. High pressure systems are more stable and often allow pollution build-ups in urbanized regions. On a local level, wind is the single most important climatological factor in determining ambient air quality. Dispersion of pollutants depends directly on the speed and direction of air flow which, in turn, is influenced by topographic features. In the Flathead Basin and other intermountain valleys in the western United States, steep north-south ridges often block the prevailing westerly winds, thus hampering dispersion.

The change in atmospheric temperatures with height can also influence ambient air quality. Normally, daytime air temperatures decrease with height above the ground, dropping about 5.5°F for each 1,000-foot gain in elevation. Under these conditions, air warmed by combustion or by contact with the ground can rise and carry pollutants upward into the atmosphere.

A temperature inversion, on the other hand, indicates air temperatures are increasing with height. During inversions, vertical mixing of the air is suppressed, and pollutants remain in the lower air layers. Surface winds also tend to be very light during inversions. Inversions occurring over extended periods of time can contribute to severe air pollutions episodes.

Precipitation can reduce air pollution levels by washing pollutants out of the atmosphere. A light, 15-

minute rainfall has been estimated to remove over one-fourth of all particles greater than 10 microns in size from the air column. Residents of western Montana benefitted from this cleansing action when steady rain finally cleared much of the volcanic dust from the air five days after the eruption of the Mount St. Helen's volcano in May 1980.

Because plants and animals have adapted to uncontaminated, clean air conditions, polluted air often interferes with sensitive physiological systems. Health effects on humans range from the short-term discomfort caused by eye irritation or noxious odors to the long-term consequences of lung cancer, emphysema, and other serious diseases. Understandably, most information on the human health effects of air pollutants derives from industrial or public health statistics, rather than from experimental testing. Correlations between ambient air concentrations and health are also complicated by synergistic effects, in which the presence of one pollutant can greatly aggravate the injury caused by another. The varying susceptibility of individuals to pollution effects further hinders a precise determination of harmful air pollution levels. As a result of these factors, most health researchers have taken a conservative approach in suggesting maximum exposure levels which provide a margin of protection for the elderly, the young, and other sensitive individuals. This conservative approach is incorporated by law into the determination of federal air quality standards.

The effects of pollution on plants has been more precisely determined through experiments with controlled pollution levels. As is the case for human health, the impacts of airborne pollutants depend upon their ambient concentrations and their physical and chemical properties. Change in leaf color (due to deterioration of the green chlorophyll tissue), collapse of cell structure, and alterations in normal growth pattern are among the most common symptoms of air pollution injury to plants.

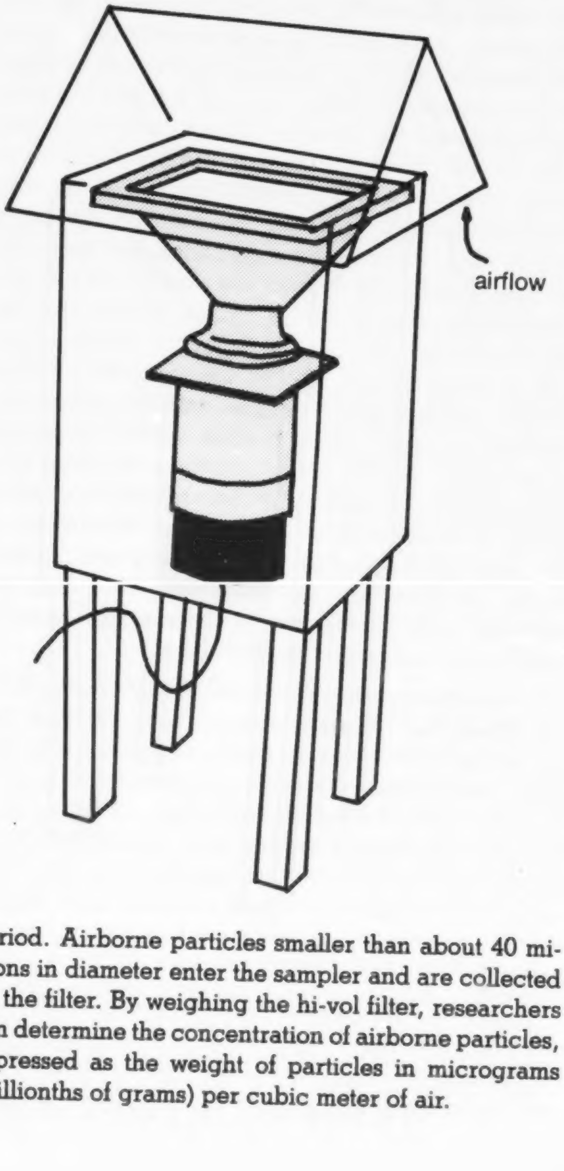
Although danger levels and impacts vary for different pollutants, the ambient concentrations needed to damage plants and animals are uniformly low when compared to the concentrations of normal constituents in the air. Many pollutants are harmful in concentrations below one part per million (ppm) by volume.

Air Pollutants

Air quality monitoring and emissions data have documented the presence of several regulated pollutants in the Flathead Basin airshed. The sources, impacts on human health and vegetation, and selected monitoring techniques for the six most important airborne pollutants in the region are reviewed below.

Particulate. The suspension of small solid and liquid particles in the air is the most common air pollution phenomenon, occurring through a wide variety of human activities and natural events. The amount of particulate matter is termed "total suspended particulate" (TSP) and is measured by a high volume air sampler (hi-vol) (Figure 4.1). The hi-vol draws a steady flow of outside air through a fiberglass filter during a 24-hour period. Airborne particles smaller than about 40 microns in diameter enter the sampler and are collected on the filter. By weighing the hi-vol filter, researchers can determine the concentration of airborne particles, expressed as the weight of particles in micrograms (millionths of grams) per cubic meter of air.

FIGURE 4.1
High Volume Air Sampler (Hi-vol)



Because the effects of particulate matter on human health depend in part upon the size of the particle, air quality researchers often differentiate between particles larger and smaller than 15 microns in diameter. (A fine human hair is about 15 microns across.) Most particles larger than 15 microns are trapped in the nose or the mucous lining of the throat and do not enter the lungs. These "nonrespirable" particles are generally not considered a human health hazard. Road dust, wind-blown soil, pollen, and industrial grinding and crushing operations are among the common sources which have a large percentage of their particulate emissions in the nonrespirable size range.

Respirable suspended particulate (RSP) consists of particles smaller than 15 microns. A dichotomous sampler, which collects RSP, simulates the human respiratory system, drawing air through filters at the typical breathing volume of six liters per minute. The sampler also separates particulate matter into a coarse fraction, containing particles between 2.5 and 15 microns, and a fine fraction, consisting of particles less than 2.5 microns. Particles in the coarse respirable fraction usually are retained in the nasal passages or the larger lung airways; fine particles can be inhaled deep into the lung alveoli, where gases are exchanged with the bloodstream. Fine particles can block this gas exchange or pass toxic or carcinogenic (cancer-causing) substances into the blood. Sources of fine particles include smoke, engine exhaust, various industrial processes and, to a lesser extent, roads and other fugitive dust sources. In addition, many air pollutants undergo complex chemical reactions, forming sulfuric acid droplets, salts, and many other forms of fine particulate pollution. The irritating and harmful "smog" particles are the end-products of airborne reactions involving car exhaust, suspended orgainc compounds, and energy from the sun.

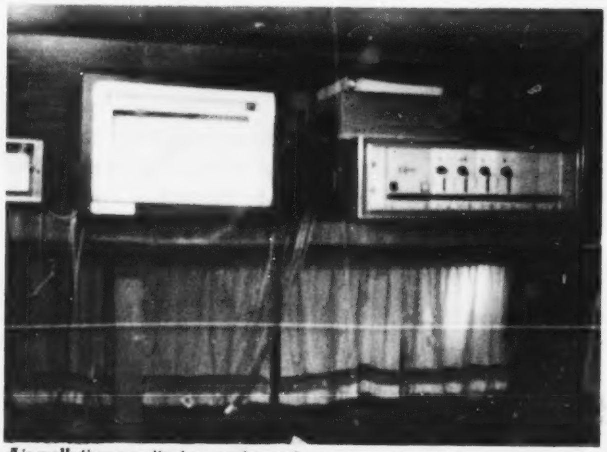
Long-term exposure to respirable particulate pollution diminishes effective lung capacity, because the inhaled particles block air passages within the lungs. Shortness of breath, wheezing, and coughing are typical expressions of acute RSP exposure, reflecting both the lack of necessary oxygen and the obstruction of breathing passages. Persons with heart or lung ailments, elderly individuals, and children are most susceptible to adverse impacts from fine particulate air pollution.

Sulfur dioxide. Sulfur dioxide, a combination of one sulfur and two oxygen atoms, is produced during the burning of fossil fuels, the smelting of mineral ores, and the processing of pulp and paper. Sulfur dioxide can contribute to air pollution directly in its gaseous form, when combined in particles called sulfates, or in solution as sulfuric acid, one of the major components of acid rain.

Public health researchers have documented that sulfur dioxide is a powerful irritant of membranous tissues in the nose, throat, lungs, and eyes, and causes increased resistance to air flow during breathing. Inhalation of sulfur dioxide may also interfere with the body's ability to clear the respiratory tract of inhaled particles, an important defense mechanism of the lungs. Airborne concentrations as low as 0.1 ppm can cause breathing difficulties in persons with bronchitis or asthma. Sulfur dioxide pollution often occurs in conjunction with fine particulate pollution and this combination has proven to be extremely damaging to respiratory function.

In plants, sulfur dioxide interferes with photosynthesis, slowing growth and killing cells at higher concentrations or with prolonged exposure. Conifers, alfalfa, and many vegetable crops are highly sensitive to sulfur dioxide pollution; visible damage to pine tree needles has been detected after only a 1-hour exposure to sulfur dioxide concentrations of 0.5 ppm. The susceptibility of plants to damage from sulfur dioxide is increased when other air pollutants, such as nitrogen oxides and ozone, are present.

Sulfur dioxide can be monitored directly by channeling air through sophisticated analyzers, or indirectly through chemical analysis of sulfates in airborne particulate matter. Sulfate analysis, an easier and less costly technique than direct suflur dioxide monitoring, was employed in the Flathead River Basin Environmental Impact Study. This technique, however, does not differentiate between sulfates formed



Air pollution monitoring equipment

from sulfur dioxide gas and those created by other sulfur-containing pollutants, such as hydrogren sulfide which can derive from the decomposition of organic matter in natural bogs. Moreover, unlike sulfur dixoide readings which indicate a local pollution source, sulfate levels are equally sensitive to pollution generated by sources at a considerable distance away. As a result of this lack of specificity for sulfur dioxide and the susceptibility to measuring long-range pollution, sulfate determinations are best used to indicate whether a problem might exist, rather than to pinpoint a specific local source of sulfur dioxide pollution.

Fluoride. Airborne fluorides, comprising gases and particles containing the element fluorine, are most commonly derived from aluminum refining, phosphate ore processing, and, to a lesser extent, coal burning. Fluoride gases are readily absorbed by vegetation, and leaves will commonly accumulate fluoride concentrations tens or hundreds of thousands of times greater than concentrations in the ambient air. Gaseous fluorides can inhibit photosynthesis and damage leaf tissues, but many plants are resistant to these effects at low or moderate pollution levels. First-year pine needles, however, are among the most sensitive of vegetative tissues to adverse impacts from gaseous fluoride pollution. Particulate fluorides accumulate as dustfall near a fluoride source and generally have less impact on vegetation than gaseous fluorides.

Livestock and wildlife can suffer secondary impacts from fluoride air pollution by eating vegetation containing or coated with fluorides. The excessive intake of fluoride causes fluorosis, a disease characterized by abnormal growth of bones and teeth, lameness, and a progressive decline in vigor.

The State of Montana monitors fluoride through chemical analysis of vegetation. The current state standard allows a maximum of 35 ppm of fluoride in forage as a growing season average and 50 ppm during any single month, although some researchers dispute the adequacy of this standard in protecting livestock from long-term injury.

Other pollutants. Nitrogen oxides derive from vehicle engines, natural gas furnaces, and other high temperature combustion operations. These compounds participate in airborne reactions which produce chemical irritants to the eyes and the respiratory system. Nitrogen oxides are readily absorbed into the bloodstream and reduce the ability of red blood cells to carry oxygen. Nitrogen oxides and their reaction products can also damage plants. Although direct monitoring of nitrogen oxide gas is expensive and time-consuming, nitrate concentrations can be determined through a simple chemical test applied to airborne particulate collected by a high-volume sampler. This nitrate reading gives relative airborne nitrogen dioxide concentrations, much in the same way sulfate concentrations indicate ambient sulfur dioxide gas levels.

Carbon monoxide gas is a non-irritating, odorless gas produced by the incomplete burning of organic fuels, such as gasoline, wood, coal, and oil. Automobiles are the major emission source, although residential heating and industrial combustion can also contribute significant amounts of carbon monoxide to the atmosphere. Red blood cells have a much greater affinity for carbon monoxide than for oxygen; as a result, inhalation of elevated levels of carbon monoxide denies the body necessary oxygen, resulting in headaches, fatigue, and eventually death. Carbon monoxide concentrations are monitored by infrared gas analyzers, which are most commonly placed near city intersections with heavy traffic flow; however, high carbon monoxide readings have been recorded in Missoula locations away from motor vehicles, indicating wood stoves are contributing to the elevated carbon monoxide levels.

Hydrocarbons encompass a large array of chemical compounds resulting from the evaporation or incomplete combustion of gasoline and other organic fuels. Automobile exhaust, oil refineries, and many industrial processes release hydrocarbons, which react readily in atmospheric reactions catalyzed by sunlight and often including nitrogen oxides. Ozone, nitrogen dioxide, and other compounds collectively termed "smog" are among the highly irritating products of hydrocarbon reactions. Polycyclic organic compounds (POCs) comprise a class of hydrocarbons commonly derived from wood smoke. Recent studies have implicated POCs as carcinogenic agents. The increasing popularity of residential wood burning has dramatically increased POC concentrations in urban areas, and these compounds may present a health hazard in intermountain valleys with poor ventilation.

Acid deposition. Transport of acidic materials from the atmosphere to the earth is termed acid deposition. When combined with precipitation, acidic compounds become acid rain or acid snow; in dry particle form, the deposition is classed as acidic dryfall. Sulfuric acid, produced in airborne chemical reactions involving sulfur dixoide gas primarily from power plant and smelter emissions, and nitric acid, derived from nitrogen oxide automobile exhaust, are the major components of acid deposition.

The most pronounced impacts of acid deposition have been observed in aquatic systems hundreds of miles downwind from major concentrations of industrial sources. Thousands of lakes in the northeastern United States and Canada are now too acidic to support fish, as a result of long-range transport of sulfuric acid from coal-fired power plants in the Ohio Valley. Acid precipitation can also affect soils by leaching nutrients and promoting the release of toxic metals from formerly stable chemical compounds. Over time, acid rain could mean greatly reduced soil productivity in widespread areas.

Acidity is measured in units of pH, with 7 being neutral, higher numbers (up to 14) indicating a progressively more basic solution, and lower numbers (down to 0) indicating more acidic solutions. A single unit change in pH reflects a tenfold difference in acidity; thus, for example, a solution with a pH of 5 is ten times more acidic than a solution with a pH of 6. The theoretical pH of precipitation from unpolluted air is 5.6; however, natural factors, including soil and vegetation influences, may alter the pH of precipitation samples.

Recent measurements of precipitation chemistry in Glacier National Park have revealed a range of pH values centered between 4.7 and 5.5, with extremes extending as low as 4 and as high as 7. Although the low readings may indicate elevated acidity in some precipitation events, researchers do not yet know whether these readings are attributable to natural causes or to the long-range transport of acidic compounds. Monitoring of precipitation chemistry in the Flathead drainage is essential because many high elevation lakes and streams have very little natural capacity to neutralize acids. These waters would be highly vulnerable to losing fish and other aquatic life from acid deposition. Continued research to establish long-term trends in pH and to investigate possible associations of specific pH readings with the geographic origin of storms sould help clarify whether man-caused acid precipitation is impacting the upper Flathead Basin.

Visibility

Visibility refers to the appearance of objects viewed through the ambient air. Visibility is often described in terms of visual range, the distance at which a large, dark object can be seen against the horizon. Other aspects of visibility include perception of color, light-dark contrast, sharpness of detail, and the three-dimensionality of topographic features.

An object is visible by virtue of the light which reflects off it and travels to the observer. During this straight path, airborne particles or gases may either

Big Mountain, Whitefish, Montana Travel Promotion Unit deflect (scatter) light in other directions, or they may absorb light and thus extinguish it. As a result of scattering and absorption, not all the light reflected from an object will reach the viewer. Particles also impair visibility by scattering extraneous light (light not reflected from the object being observed) into the line of sight. This added light appears as haze, which makes objects more difficult to distinguish from their surroundings and reduces visual range.

Particles between 0.1 and 1 micron most readily scatter visible light. Particles in this size range generally consist of smoke, metallurgic fumes, and the products of airborne reactions involving sulfur dioxide, nitrogen oxides, and hydrocarbons. Large particles do not impair visibility to the same extent as small particles; for example, an ambient air concentration of 20 ug/m^3 of particles 5 microns in diameter is needed to equal the light scattering caused by a concentration of only 1 ug/m^3 of particles 1 micron in size.

Nitrogen dioxide is the only common pollutant that, in its gaseous form, has a significant effect on visibility. Nitrogen dioxide molecules absorb certain wavelengths of visible light and impart a brown color to the air, as is characteristic of the Los Angeles airshed with its concentrated automobile emissions.

The theoretical limit of visibility through clear air on the earth surface is about 160 miles, but even a very small amount of airborne particulate matter will reduce visual range to less than 100 miles. In arid, rural locations in the West, a visual range of 65 to 85 miles is common. Visibility of 20 to 50 miles is frequently recorded in urban areas, but during conditions of extreme pollution, precipitation, or fog, visual range may drop to less than one mile.

Visual range is not considered a good indicator of air quality because natural changes in the water vapor content of the air (humidity) can drastically affect this measurement. In the Flathead Basin air quality study, visibility readings were taken by an integrating nephelometer, an instrument which uses an artifical light source in an enclosed, meter-long chamber to measure the scattering of light by airborne particles. Nephelometer readings are expressed as "scattering coefficients", with a higher coefficient indicating more scattering of light by particles and thus reduced visibility. Scattering coefficients can be related to visual range, if dry air conditions are assumed. For example a scattering coefficient of 23 indicates that airborne particulate is limiting visual range to about 10 miles; a coefficient of 3 translates to a range of over 60 miles. In both cases, the actual distance which an observer could see would be lower than the calculated visual range because vapor in the ambient air hinders light transmission, an effect not measured by the nephelometer.

The Flathead Basin Airshed

During the five-year Flathead River Basin Environmental Impact Study, researchers monitored air quality over a broad range of geographic and human influences. Remote rural monitoring sites were located in the North Fork Valley, in the Swan Valley, and in the Mission Valley at Ninepipe National Wildlife Refuge. Sampling in developed areas focused on urban population centers within the upper Flathead River Valley and the Mission Valley.

Ambient air monitoring emphasized particulates, both because of the region's periodic high levels of particulate pollution and because particulates pose the most serious health threat to basin residents. Total suspended particulate was sampled at 15 locations; dichotomous samplers for respirable particulate were operated at six sites. Airborne concentrations of sulfates and nitrates were analyzed from particulate matter collected at 10 locations. Researchers monitored visibility through a series of instruments located at the Glacier International Airport, centrally located between Kalispell, Whitefish, and Columbia Falls. The Flathead Basin study also incorporated results from the ongoing fluoride monitoring program near the Anaconda Aluminum Company to complete a comprehensive assessment of important pollution influences within the basin.

An inventory of air pollution sources was conducted in conjunction with the ambient air monitoring network. The inventory documented the amounts of pollutants emitted from each major point source within the basin, as well as the total emission contribution of important nonpoint sources. The nonpoint source inventory included particulates and sulfur dioxide, while point source information covered particulates, sulfur dioxide, carbon monoxide, hydrocarbons, and nitrogen oxides.

An intensive meteorological study supplemented the Flathead Basin air quality monitoring network and emission inventory. Surface wind speed and direction were recorded at eight locations; upper air movement was monitored six times weekly by balloons launched from the Glacier International Airport and Ninepipe National Wildlife Refuge. Balloon and radar soundings also provided a profile of the air temperature in relation to elevation. The wind data and temperature readings indicated the ability of the airshed to disperse pollutants and the direction of travel of air emissions.

Emission Sources

Particulate. Dirt and gravel roads contribute about three-fourths of the total particulate load carried by the Flathead Basin airshed (Table 4.2). Almost 90,000 tons of road dust enter the atmosphere annually, the result of an aggregate 45 million miles driven on unpaved roads in the basin each year. Residential areas on the outskirts of the larger cities produce the greatest amount of road dust because of their combination of heavy traffic volume and many gravel roads. Most road dust particles are larger than 15 microns in diameter and not considered respirable; however, the fine glacial sediments which make up many of the valley road beds can be ground into the respirable size range in areas of heavy traffic use.

TABLE 4.2
Flathead Basin Emission Inventory Summary

Source	Particulates (tons/yr)	SO_2 (tons/yr)
Traffic Dust on Dirt and Gravel Roads	88,539	
Slash Burning	23,704	
Traffic Dust on Paved Roads	853	
Wildfires	356	
Vehicle Emissions	353	161
Agriculture Activities	290	32
Residential, Commercial, Institutional Fuel Combustion	245	532
Aggregate Storage	75	
Railroads	44	101
Aircraft	1	2
	114,460	828

Source: M.D.H.E.S. Nonpoint Source Inventory

The intentional burning of logging residue, or "slash", is the second most important source of particulate pollution in the basin. Slash burning adds over 23,000 tons of smoke to the airshed annually, which equals about one-fifth of the regional particulate load. Much of the smoke produced by slash burning is respirable particulate. The plume of smoke from intensely hot slash fires characteristically rises to great heights and disperses relatively low concentrations of pollutants over wide areas. Smoldering slash fires, on the other hand, yield up to 10 times more particulate per weight of fuel burned and the smoke plume is concentrated in a relatively small area.

Soil tilling for agriculture exposes soil to wind erosion, but most wind-blown soil particles are too large to remain suspended in the air. As a result, the contribution of agricultural activities to the airborne particulate load is relatively minor.

Motor vehicle exhaust, wood smoke from domestic heating, and combustion products from the residential and commercial use of fossil fuels are major nonpoint particulate sources in urban areas. Although these emissions total less than two per cent of basinwide particulate, they contribute significant amounts of fine particulate to the airshed. A 1981 survey of residential wood burning indicated that 30% of the homes in Kalispell burn wood as either a primary or auxilliary heat source, producing an estimated 600 tons of primarily fine particulate each year. In general, ambient levels of fine particulates relate directly to population density, reflecting the urban concentrations of cars, homes, and small businesses which produce much of the fine particulate load.

Most industrial point sources of particulate matter are located near urban centers and thus constitute important local sources of particulate (Table 4.3). A particle board plant, two plywood plants, and six sawmills are located in the vicinity of Kalispell, Columbia Falls, and Whitefish in the upper Flathead River Valley; together, these sources emit almost 1,000 tons of particulate annually. The Anaconda Aluminum Company plant north of Columbia Falls releases an estimated 268 tons per year. Other point sources of particulate pollution include lumber mills at Pablo, Polson, and Olney, along with minor particulate contributions from four asphalt plants near Kalispell. Most industrial particulate is in the respirable size category.

Sulfur dioxide. Emissions of sulfur dioxide gas are derived primarily from point sources, in sharp contrast to the non-point origin of most airborne particulate. The Anaconda aluminum smelter is the chief source, annually releasing 2,646 tons, or about 75% of total sulfur dioxide emissions in the Flathead Basin. Compared to other metal smelters in Montana, sulfur dioxide emissions from the Anaconda facility are relatively low. (less than 10% of the annual emissions from the

TABLE 4.3
Point Source Emission Estimates

Source	Location	Sulfur dioxide (tons/yr)	Particulates (tons/yr)*
ARCO Aluminum	Columbia Falls	2646	268
Stoltze Land and Lumber	Columbia Falls		620
Plum Creek Lumber	Pablo		175
Flathead Lumber	Polson		371
American Timber	Olney		113
Plum Creek Lumber	Columbia Falls		335
Plum Creek Lumber	Kalispell		316

*Fugitive emissions associated with vehicle traffic are included

Source: Montana Air Quality Data and Information Summary for 1981, M.D.H.E.S.

ASARCO lead smelter in East Helena and only about 2% of the sulfur dioxide released by the Anaconda copper smelter when it was in operation prior to 1982). Small industrial sources of sulfur dioxide in the Flathead Basin include plywood and particle board manufacturing and dimension lumber processing.

The major nonpoint source of sulfur dioxide is the combustion of fuel oil by residential, commercial, and small industrial users. About one ton of sulfur dioxide is released for each 25,000 gallons of fuel oil burned. Overall, 532 tons, or 15% of the total sulfur dioxide load, are produced from nonpoint fuel oil sources. Annual sulfur dioxide emissions from motor vehicles total over 160 tons and depend on both fuel type and engine efficiency. Gasoline-powered automobiles have the lowest sulfur dioxide emissions; large diesel trucks release 22 times as much sulfur dioxide per mile as passenger cars. Railroad engines, which also burn diesel fuel, contribute over 100 tons of sulfur dioxide to the airshed each year.

Other pollutant sources. The only source of airborne fluorides in the Flathead Basin is the Anaconda Aluminum Company, which annually emits about 130 tons of gaseous and particulate fluoride. Carbon monoxide and hydrocarbons, both symptomatic of incomplete fuel combustion, enter the basin airshed primarily from motor vehicles exhaust, residential wood smoke, and wood processing operations. Nitrogen oxide emissions derive from automobiles and most wood products facilities.

Monitoring Results

Particulate. Particulate concentrations within the Flathead Basin clearly displayed the influence of population density (Table 4.4). The central business districts of Kalispell and Columbia Falls experienced consistently high total suspended particulate (TSP) levels, due to a concentration of population-related nonpoint sources, along with some industrial point sources. Annual TSP averages in Columbia Falls exceeded the Montana ambient air standard (75 ug/m^3) during all five years of monitoring, averaging 128 ug/m^3 through the monitoring period. Readings in Columbia Falls also exceeded the Montana daily standard, which sets a maximum TSP reading of 200 ug/m^3, not to be exceeded more than once a year.

The Strom and Universal Athletic sites in downtown Kalispell exceeded the Montana annual TSP standard during four of the five years of monitoring, and had a five-year average of 87 ug/m^3. The standard for daily maximum TSP readings was exceeded during three years.

Air quality analysts consider road dust to be the most significant contributor to particulate pollution in Columbia Falls, and the reduced TSP readings during 1982 were probably related to the completion of a major street re-paving project in the downtown area. Point source emissions, including the Anaconda Aluminum Company plant and the Plum Creek sawmill and particle board plants, may also affect the local airshed, but emissions from these sources generally do

TABLE 4.4
Flathead Basin TSP Levels
Maximums, (Second High Reading), and [Arithmetic Average]*

	1978			1979			1980			1981			1982		
Site	Max	(2nd)	[Ave]	Max	(2nd)	[Ave]	Max	(2nd)	[Ave]	Max	(2nd)	[Ave]	Max	(2nd)	[Ave]
Moose City	40	(18)	[15]	15	(12)	[10]									
Polebridge										89	(62)	[30]	89	(60)	[19]
Columbia Falls-NAAC	59	(56)	[25]	64	(63)	[29]	106	(81)	[30]	89	(83)	[30]	49	(45)	[18]
Columbia Falls-Anders	425	(423)	[134]	484	(390)	[145]	498	(455)	[129]	494	(390)	[148]	241	(225)	[85]
Whitefish										144	(128)	[73]	138	(130)	[55]
Kalispell-GIA				140	(120)	[56]	309	(232)	[62]	134	(103)	[39]	94	(89)	[31]
Kalispell-Strom	110	(105)	[65]	343	(289)	[90]									
Kalispell-Universal Athletic							296	(202)	[103]	211	(186)	[90]	234	(232)	[85]
Kalispell-Evergreen							169	(138)	[67]	170	(159)	[65]	176	(176)	[54]
Bigfork				112	(103)	[43]	134	(102)	[42]	109	(84)	[32]	80	(78)	[29]
Polson				202	(191)	[80]	177	(159)	[62]	174	(111)	[44]	100	(95)	[42]
Ronan	170	(120)	[48]	405	(311)	[109]	220	(175)	[88]						
Ninepipes							42	(35)	[21]	142	(55)	[24]	71	(54)	[18]
Swan River													122	(85)	[23]

*All values in micrograms per cubic meter

not travel directly toward downtown Columbia Falls. Particulates in Kalispell derive from a combination of wood smoke and road dust, including fine particles from paved roads; industrial point sources dispersed through the upper Flathead Valley probably also add to the airborne particulate load measured at Kalispell.

The particulate sampler located about one mile east of downtown Polson indicated generally good air quality, despite its proximity to a small lumber mill. The annual average reading of 80 ug/m^3 during 1979 occurred as a result of highway construction at a nearby intersection; during 1981 and 1982, TSP readings at Polson averaged only 43 ug/m^3. Near Ronan, the high volume sampler recorded elevated TSP levels because of its proximity to a well-traveled gravel road, and the site was discontinued in 1980.

Particulate readings from Whitefish were unexpectedly high, and nearly equaled the Montana annual average standard during 1981. Whitefish readings were significantly higher during the winter than the summer, even though unpaved roads are sealed by winter ice. This finding, coupled with the lack of nearby point sources, strongly suggests that wood smoke from residential home heating was a major factor contributing to the elevated TSP readings in Whitefish.

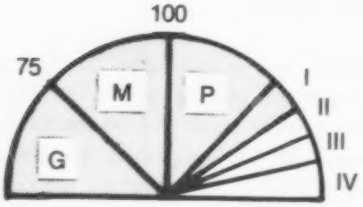
The effect of population on particulate concentrations is indicated by a comparison of TSP levels from the Evergreen area and the Glacier International Airport, both located several miles north of Kalispell. Evergreen, a densely developed residential area with numerous dirt roads, had particulate counts averaging

60 ug/m³ during 1981 and 1982. The nearby Glacier International Airport, which has relatively little surrounding development, averaged only 35 ug/m³ during the same two-year period. Samplers located at Bigfork and two miles north of Columbia Falls also showed low particulate readings typical of rural sites.

Air quality monitoring stations at Moose City and Polebridge on the North Fork; at Ninepipe National Wildlife Refuge, in the Mission Valley and at the Swan River Youth Camp 12 miles south of Swan Lake recorded extremely low TSP levels. These sites are remote from development, with dust from unpaved roads and smoke from slash burning and occasional forest fires constituting the only significant sources of airborne particulate matter. During winter, road dust and smoke contributions are negligible, and monitoring equipment is essentially measuring what the ambient TSP concentrations of Flathead Basin air would be in the absence of human activity. These winter background readings at the Swan River site average 6 ug/m³.

The air quality classification system utilized by the Missoula City-County Health Department indicates the degree of public health concern associated with varying levels of particulate air pollution (Figure 4.2).

FIGURE 4.2
Missoula City/County Health Board
Pollution Alert System
Stage I Alert



Air outlook

G = Good (less than 75 micrograms of particulate per cubic meter of air);
M = Marginal (under 100 micrograms);
P = Poor (under 150 micrograms);
I = Stage I alert (under 300 micrograms);
II = Stage II warning (under 625 micrograms);
III = Stage III emergency (under 875 micrograms);
IV = Stage IV crisis (875 micrograms and up).

Ambient particulate readings below 75 ug/m³ represent "good" air quality, which grades into "marginal" and "poor" with increasing particulates. Readings above 150 ug/m³ trigger a Stage I Alert in Missoula, during which outdoor burning is prohibited and residents are requested to refrain from using wood stoves. Particulate counts above 300 ug/m³ initiate the Stage II Warning. Children and sensitive individuals are advised to remain indoors, and wood stove use is prohibited. Further restrictions on residential, vehicular, and industrial emissions are imposed in the event particulate counts reach the Stage III Emergency or Stage IV Crisis levels. Missoula particulate readings have reached a recorded high of 676 ug/m³, exclusive of the elevated counts during the ashfall from the Mt. St. Helens volcano.

The relative concentrations of respirable suspended particulate (RSP) in the Flathead Basin mirrored the total particulate counts (Table 4.5). The downtown Kalispell and Columbia Falls sites recorded the highest levels of particulates smaller than 15 microns in diameter. Polson and the Glacier International Airport had somewhat lower RSP concentrations, while Polebridge and Ninepipe consistently gave the lowest readings.

Concentrations of the fine RSP fraction (particles smaller than 2.5 microns) generally varied less between sites than did concentrations of the coarse RSP fraction (particles between 2.5 and 15 microns). The relative consistency of fine RSP concentrations reflects the tremendous mobility of small particles in the atmosphere. These particles, primarily generated in urban areas, can remain suspended in the atmosphere for long periods and will disperse into remote sites. Particles in the coarse fraction, along with particles larger than 15 microns, tend to settle out of the air and, as a result, ambient concentrations fall off more rapidly away from the particle source.

Sites with high TSP levels showed a significant seasonal variation in particulate counts. In general, two peaks were evident—one extending from early spring into early summer and the other occurring in early summer and early fall. The high spring particulate counts appear to be associated with the freeing of road dust through the melting of the lower elevation winter snowpack. Autumn particulate increases may be associated with slash burning and the predominance of low wind speeds, which hamper the dispersion of road dust and other pollutants.

Particulate readings were lower at all monitoring stations during 1982 than 1981. The regional meteorology during 1982 was characterized by fewer tempera-

TABLE 4.5
Flathead Basin — Respirable Particulates
Micrograms Per Cubic Meter
Size Classification Microns

Site	Year	2.5		2.5-15		15	
		Max	Mean	Max	Mean	Max	Mean
Kalispell Univ. Athl.	80(12)	42.9	17.3	144.3	41.5	187.2	58.8
Polson	79.80(10)	27.0	13.2	100.6	31.1	125.5	44.3
Col. Falls-Anders	80(10)	28.4	15.1	235.5	63.4	263.5	78.5
Flathead Airport	79(10)	41.4	14.8	68.1	25.0	109.5	39.8
Ronan-Ninepipes	81(11)	44.8	8.3	66.0	10.9	83.6	19.2
Polebridge	79(12)	24.7	9.0	88.6	11.2	106.0	20.2

( ) — parentheses denotes number of sample months

ture inversions and better conditions for dispersal of pollutants, thus leading to lower ambient particulate levels.

Although road dust and smoke from slash burning contribute a combined 95% of the regional particulate load, several factors mitigate the potential adverse impacts of these particulate sources. First, most road dust particles are non-respirable and will be trapped in nasal or throat passages without entering the lungs. Also, road dust levels are much reduced during winter, when melted or frozen snow and ice seal road surfaces and prevent most dust from becoming suspended. Thus, during the severe winter temperature inversions when the potential for pollution build-up is greatest, road dust is making only a small contribution to the airborne particulate load. Finally, the remote location of most slash fires and the smoke management program, which restricts burning during periods of poor air dispersion, generally prevent excessive smoke concentrations in populated areas from slash burning. Neither slash burns nor wildfires occur during the winter inversion season.

Rural road west of Flathead Lake

Residential wood burning, on the other hand, presents a greater public health hazard than indicated by simple emission totals. Wood smoke produces primarily respirable particulates, some of which occur as polycyclic organic compounds, a cancer-causing class of hydrocarbon air pollutants. Smoke emissions are concentrated in the residential areas and thus impact a large segment of the population. Moreover, the wood burning season occurs primarily in late autumn and winter, thus coinciding with the periods having the highest frequency of temperature inversions and the poorest conditions for pollutant dispersal. In recent years, thousands of western Montana residents have converted to wood burning as an alternative to rising energy costs, and this trend is expected to continue. As noted above, an estimated 30% of the homes in Kalispell now burn wood as either a primary or auxiliary heat source.

Sulfates and nitrates. Concentrations of sulfates and nitrates followed a very similar pattern to particulate levels (Table 4.6). Most rural sites gave consistently low readings, while industrialized urban areas recorded the highest levels. The lowest sulfate readings were recorded at Ninepipe, with a 1.6 ug/m^3 average, and at Swan River, with a 1.9 ug/m^3 average. Point and nonpoint sources of sulfur dioxide are most prevalent in the upper Flathead River Valley, where monthly average sulfate readings ranged up to 5.7 ug/m^3. The highest daily sulfate reading was 12.8 ug/m^3, recorded in February 1978 at the Columbia Falls site one mile north of the Anaconda Aluminum Company. Although this rural site was generally upwind from the aluminum plant, periodic elevated sulfur dioxide exposures did occur when southerly winds carried stack gases northward.

Polebridge experienced unexpectedly high sulfate readings for its remote location, possibly the result of long-range transport of sulfur-containing air pollutants from natural gas developments in southwestern Alberta. One major gas well "blowout" near Edmonton during autumn 1982 brought a faint sulfurous smell to the air in the Flathead Basin and many north-central Montana locations.

Concentrations of airborne nitrates generally tracked the relative abundance of automobiles, the dominant emission source. Monthly average readings were highest in downtown Kalispell and lowest at the Moose City, Polebridge, and Swan River sites.

Other pollutants. Vegetation analysis for fluorides during 1982 yielded average concentrations between 5 and 11 ppm during the growing season and between 3 and 18 ppm for individual monthly averages. These readings were well below Montana standards for fluoride in forage.

Due to the absence of major point sources or excessive nonpoint influences, ambient air monitoring was not conducted for other pollutants in the Flathead Basin.

Visibility. Monitoring at the Glacier International Airport demonstrated severely reduced visibility from October through March, and relatively good visibility from April through September. The highest monthly scattering coefficients occurred in January, 1979, with an average reading of 32. This coefficient would translate into a visual range of about seven miles under dry air conditions. The highest single scattering coefficient measured was 75 during February, 1979, indicat-

TABLE 4.6
Flathead Basin Sulfates & Nitrates
Parts Per Million

Site		1980			1981			1982		
		Mean	1-High	2-High	Mean	1-High	2-High	Mean	1-High	2-High
Polebridge	NO_3				0.1(8)	0.4	0.3	0.2(12)	0.5	0.5
	SO_4				3.2(8)	4.9	4.9	3.0(12)	6.5	5.7
Bigfork	NO_3	0.7(12)	3.9	3.8	0.7(12)	3.0	2.8	0.5(10)	2.0	1.8
	SO_4	3.4(12)	8.0	6.5	2.4(12)	6.5	5.1	2.0(10)	7.8	6.6
Whitefish	NO_3				1.0(5)	2.0	1.7	0.9(12)	3.0	2.4
	SO_4				2.5(5)	4.7	4.3	1.9(12)	6.2	5.9
Glacier International Airport	NO_3							0.8(12)	3.9	3.2
	SO_4							21.(12)	10.7	6.6
Kalispell Universal Athletics	NO_3	1.3(12)	5.9	5.5	1.1(12)	3.8	3.7	1.0(12)	3.0	2.9
	SO_4	4.6(12)	8.8	7.1	4.2(12)	8.0	7.9	3.1(12)	9.0	7.9
Polson	NO_3	1.0(12)	3.5	3.1	0.9(12)	3.8	3.4	0.9(12)	2.8	2.6
	SO_4	3.9	6.6	6.6	2.7(12)	6.6	6.2	2.4(12)	7.2	7.0
Ronan-Ninepipes	NO_3				0.8(12)	3.4	3.0	0.7(12)	3.4	3.3
	SO_4				1.6(12)	4.9	4.4	1.1(12)	6.6	6.5
Swan River	NO_3				0.0(1)	0.0	0.0	0.1(12)	0.5	0.5
	SO_4				1.9(1)	2.1	1.8	2.7(12)	6.5	5.6

( ) — parentheses denotes the number of sample months ing particles in the ambient air were limiting potential visible range to just over three miles. Average coefficients of 6 to 8 were recorded for six consecutive months during the warm season of 1980, for an average visual range of about 30 miles, excluding water vapor effects.

Periods of reduced visibility were closely correlated with high concentrations of particles smaller than 2.5 microns, as measured by the dichotomous sampler. This correlation confirms the dominant effects of fine particulate matter in scattering light and reducing visibility. The seasonal occurrence of visibility impairment relates to the high frequency of stagnant air conditions during the cool season. Temperature inversions and the lack of wind ventiliation trap air emissions in the valley locations and allow buildups of sulfates, nitrates, and other fine particulate matter. The cool season also brings an increase in particle sources, with most slash burning occurring in late autumn and most residential wood burning taking place during winter.

The State of Montana has adopted a scattering coefficient of 3 as a legal standard for visibility in mandatory Class I airsheds only. In the Flathead Basin, this standard applies to Glacier National Park and and Bob Marshall and Mission Mountain wilderness areas. Protection of visibility is a major goal of the federal Clean Air Act.

Meteorology

Major air currents from the Pacific Coast of Washington, British Columbia, and Alaska carry most of the weather systems that reach western Montana. In the Flathead Basin, this flow aloft is expressed by the prevailing westerly and northwesterly winds, which dominate upper air movements. These winds average over 16 miles per hour, measured at an altitude of 1500 meters (about a mile) above the Glacier International Airport. The highest wind speeds aloft are recorded in winter; the lightest upper air winds occur in summer.

As altitudes below 500 m, the topography of the Flathead Basin is the dominant influence on local air flow patterns. Wind speeds drop with decreasing height above the ground, as the north-south oriented mountain ranges impede the westerly components of upper air movement. At an altitude of 100 m, afternoon winds average 9 mph, or just over half of the velocity recorded at 1500 m. The mountains also affect wind direction, channeling air through the valleys. Upper air currents are generally aligned along a north-south axis below 500 m altitude in the afternoons and below 200 m in the mornings.

Detailed surface wind measurements taken at eight stations in the Flathead Basin confirm the overriding influence of topography on wind direction. At all locations, the two most common winds were from the north and the south, paralleling the surrounding mountain ranges. The least common wind directions were east through southeast, due to the barrier to air flow presented by the steep mountains on the eastern edge of the Flathead Basin.

Other topographic features also influence wind direction. Gusty southerly winds were often recorded from Flathead Lake to Kalispell during warm afternoons from late March through September. These winds are generated as air over the land rapidly warms and rises, creating a draft which draws air from the cooler lake surface. Polson at the south end of Flathead Lake experienced similar water-to-land breezes each summer, resulting in northerly afternoon winds. The lake effect was reversed during winter, when dominant wind directions were from the cooler land surface to the warmer lake surface.

Mountain valley sites in the upper Flathead River Valley demonstrated significant daily wind shifts. During nighttime, the colder, high elevation air flowed downslope to the valley floors; after sunrise, this pattern was reversed and upslope winds developed.

Surface wind velocities were generally low throughout the Flathead Basin. Poor wind ventilation inhibits dispersion of pollutants and thus increases the likelihood of elevated pollution concentrations.

A high frequency of daytime inversions in winter, characteristic of many intermountain valleys in the northern Rockies, further limits the ability of the Flathead airshed to disperse pollutants. An inversion indicates that air temperatures are rising with increasing elevation above the ground. Typically, temperature inversions occur at night when air in contact with the earth cools more rapidly than upper air. As a result, warmer air rests atop cooler air in stable layers with little vertical circulation. When the sun rises, heat radiating off the ground warms the surface air, which rises and thus creates turbulence which breaks the hold of the inversion. Pollutants trapped near the ground by nighttime inversions will be carried upward by this vertical air movement and dispersed by upper air winds.

Air temperature profiles taken above the Glacier International Airport revealed that nighttime inversions were present more than 90% of the time throughout the year. During April through October, these inversions generally dissipated soon after sunrise, and the afternoon frequency of warm-season inversions was only 12%. During the cool season, however, the reduced amount of solar radiation was often ineffective in heating the earth surface and stimulating air movement. As a result, temperature inversions persisted into the afternoon 62% of the time from November through March.

The relationship between inversions and pollution build-ups is mediated by the meteorological "mixing height", which is the maximum altitude to which surface air (including airborne emissions) can rise before dispersing laterally through the atmosphere. Afternoon mixing heights when no inversions are present generally range from 1,500 m to an unlimited height at the Glacier International Airport. Pollutants thus dispersed through a large air volume, and there is little potential for locally elevated pollution concentrations.

Checking air monitoring equipment

During winter, however, afternoon mixing heights in the Flathead airshed average 200-700 m, confining pollutants to a relatively small air volume. With severe temperature inversions, emissions stay at or below the height at which they are released into the atmosphere. A sheet-like, or "laminar", flow results, as is evidenced by the thin, horizontal plumes leaving chimneys and industrial smokestacks. Pollutants confined to the lower air layers during inversions can cause adverse public health impacts if concentrations become high enough.

Clear, calm winter weather conditions can lead to prolonged inversions lasting days or even weeks in intermountain valleys. Cold air settling on valley floors promotes the condensation of water vapor into droplets which quickly freeze; this ice fog, in turn, reflects solar radiation and prevents the ground from warming. The low angle of the sun's rays and the reflective snow cover further inhibit solar heating of the ground and the surface air layer. When winds are light, as often occurs under the influence of high pressure systems, no mixing of air layers occurs. The cold air remains trapped below warmer air, and pollutant concentrations rise steadily until weather conditions change.

Week-long inversions have resulted in extreme particulate pollution in the densely populated Missoula Valley, where concentrated residential wood burning and motor vehicle use are coupled with numerous industrial sources. The Flathead Basin has avoided such severe episodes, both because of a much lower number of sources and because the broader valley topography and convective air flow from Flathead Lake help disperse pollutants. Winter inversions lasting several days, however, do occur in the populous upper Flathead River Valley and are accompanied by elevated particulate counts. The more confined mountain valleys, such as the North Fork and the Swan, have experienced periods of 10 days or more when temperature inversions have prevented any ventilation of the airshed. The lack of pollution sources in these remote regions has kept ambient pollutant levels very low, despite such prolonged air stagnation.

Summary of Conditions in the Flathead Basin Airshed. Ambient air monitoring conducted through the Flathead River Basin Environmental Impact Study revealed generally very good air quality in the region. Low concentrations of particulate matter, sulfates, and nitrates characterize most of the airshed, as indicated by measurements taken at widely distributed rural locations.

Within this reservoir of clean air, however, localized pollution problems exist. Particulate levels in some urban centers have frequently exceeded state standards. This airborne particulate, which includes a high proportion of respirable particles, is primarily generated by population-related nonpoint sources, such as road dust, wood smoke, and motor vehicle exhaust.

Light winds and frequent temperature inversions inhibit air dispersion and compound the effects of concentrated urban emission sources. The populous valley locations in particular are susceptible to air stagnation and attendant pollution build-ups.

The increasing amount of residential wood burning threatens to aggravate fine particulate pollution levels in areas of concentrated population. Wood smoke emissions reach a peak during late autumn and winter, when temperature inversions often inhibit the dispersion of pollutants.

The existence of four federal Class I air quality regions in the Flathead Basin offers a large measure of protection against the impacts of major new industrial sources of pollution. Dust and processing emissions from potential coal mining operations in the Canadian Flathead, however, are not regulated by United States air quality standards and could substantially degrade air quality in the North Fork Valley and Glacier National Park.

Modeling the Flathead Basin Airshed

Construction of new industrial point sources and continued population growth, with attendant wood smoke, road dust, and vehicular emissions, are potential sources of additional air pollutants to the Flathead Basin airshed. Regional concern for clean air, public health, and the protection of the pristine Class I airsheds underscores the desirability of being able to predict the impacts on air quality before development proceeds. In this manner, policy decisions on permitting, siting, and pollution control abatement can be made prior to any possible air quality degradation.

Information gathered during the five years of the Flathead River Basin Environmental Impact Study has allowed researchers to develop a predictive model of how air emissions will affect the Flathead Basin atmosphere. The model relies on the detailed meteorological data collected from Kalispell, Columbia Falls, Bigfork, Polson, Ninepipe, and Polebridge. For each of these six locations, researchers have constructed an hourly record for an entire calendar year of wind speed and direction, mixing height, temperature profile, and inversion characteristics.

The meteorological data was combined with the inventory of existing emission sources in the Flathead Basin to describe the six local airsheds (Table 4.7). The final component of the model was the description of how pollutants move in the atmosphere. In relatively open sites of Kalispell, Columbia Falls, Bigfork, Polson, and Ninepipe, pollutants disperse downwind and concentrations fall off rapidly with increasing distance from a source. In Polebridge along the North Fork, pollutants are confined to a narrow valley and continued emissions may result in pollution buildups; a separate "box" model was developed to simulate the North Fork Airshed.

The successful development of the airshed models provides the capability to predict the air pollution consequence of new emission sources for the six Flathead Basin regions. For example, air quality specialists might wish to "site" two miles west of Kalispell a hypothetical industrial source emitting 1,000 tons of particulate annually. Subsequent computer analysis would give the expected annual average total suspended particulate concentration in Kalispell, the percent increase in particulates attributable to the new source, and the worst case of daily particulate levels. Where meteorological data allows, results can be expanded over a wide geographic range; thus, the impacts on air quality in southwestern Glacier National Park can be determined for a new emission source in Kalispell.

TABLE 4.7
Flathead Basin Airshed Model

Area and Point Source Particulate Emmission Estimates (tons/yr.)

	Area Sources	Point Sources
Ninepipe airshed	18,929	175
Polson airshed	1535	312
Bigfork airshed	2409	—
Kalispell airshed	17,878	417
Columbia Falls airshed	3795	1,397
North Fork airshed	4912	—

Using the box model developed for the North Fork, researchers have modeled the impacts of the Cabin Creek coal mine on the North Fork airshed. The results indicate that emissions of particulate and sulfur dioxide from the mine site would exceed Montana Class I air quality standards in nearby portions of Glacier National Park. The maximum increase in daily particulate average is expected to be about 60 ug/m^3. The annual average particulate increment in the North Fork just south of the international border is predicted to be 20 ug/m^3 as a result of the Cabin Creek mine. Sulfur dioxide concentrations in the park would increase to measurable, but still low levels, with an annual average increase of 7 ug/m^3 (0.0026 ppm).

The computer tapes of the Flathead Basin airshed model will be maintained at the Air Quality Bureau of the Montana Department of Health and Environmental Sciences. The air quality impacts of potential new sources located within the six modeled regions can now be simulated readily and inexpensively, as a result of the detailed meteorological background gathered through the Flathead River Basin Environmental Impact Study.

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[1] A micron is one millionth of a meter.

CHAPTER V
FLATHEAD BASIN AQUATIC RESOURCES

University of Montana Archives, M. J. Elrod Collection, Somers Bay, Flathead Lake

Montana Travel Promotion Bureau

If asked to recall their experiences with Flathead waters, most basin residents could draw on a wealth of sensory images, perhaps including:

> the savory flavor of home-canned kokanee salmon;
>
> a rejuvenating blue-water plunge after an indulgent basking on a Flathead Lake beach;
>
> the brilliance of an alpine flower garden, silently irrigated by meltwater from a remnant glacier;
>
> the insistent tug of a North Fork cutthroat trout that mistook a fur-and-feather ant for its real-life model;
>
> the visceral thrill of six-foot freefall, as gravity reclaimed a river raft momentarily airborne between Middle Fork standing waves;
>
> the reassuring "thud" of the dock minutes before a black, southwestern squall transformed placid Woods Bay into a white-capped sailor's nightmare; and
>
> a snowy vision of bald eagles, like holiday ornaments adorning the treetops along McDonald Creek.

These varied experiences are all linked to the diverse recreational, fish and wildlife, and scenic values which characterize the Flathead drainage. The quality of life and the economic well-being of basin residents depends upon the maintenance of the pristine character of the river and lake ecosystem.

Although the importance of the Flathead watershed is widely recognized, this recognition by itself does not insure conservation. Development of timber, hydropower, agricultural and residential land, and other natural resources have dramatically altered the basin environment. Without appropriate safeguards, the cumulative effects of continued land-use changes could jeopardize both water quality and the biological communities of the Flathead drainage.

During the five-year Flathead River Basin Environmental Impact Study, scientists documented the processes that give Flathead waters their unique natural values. The findings underscored how the upper Flathead River drainage and Flathead Lake function as a single ecosystem, with the integrity of each part vital to the aquatic system as a whole. Sediments, nutrients, and other materials generated by land uses and by natural processes are carried downstream through the watershed into the lake; upstream links focus on the several important game fish species that migrate from the lake to make use of spawning and rearing areas in river tributaries.

The boundaries for research on the aquatic ecosystem were defined as the limits of the Flathead drainage above Kerr Dam. This study area encompasses Flathead Lake and all of its tributary watersheds, including the three forks of the Flathead, the mainstem Flathead River, and the Swan River. Studies of the migratory fisheries focused on the lake and the free-flowing components of the river system; research on other aspects of aquatic ecology also considered waters above Bigfork Dam and Hungry Horse Dam. Scientists gave high priority to documenting conditions on the North Fork because of the potentially severe environmental impacts of the proposed coal mine at Cabin Creek in the British Columbia portion of the North Fork.

The Flathead River Basin Environmental Impact Study documented some fascinating aspects of the aquatic ecosystem. Fishery studies catalogued the annual journey of cutthroat and bull trout from Flathead Lake to spawning beds in small tributaries, a round-trip of up to 300 miles. These native fishes require the widely different habitats provided by the lake and the river system to complete their life cycles. Aquatic insect investigations disclosed a hidden streambottom world where over a hundred different species coexist at a single site, despite an extremely unproductive environment. This evolutionarily fine-tuned community fills a key ecological role by channeling biological energy through the aquatic system. Studies of nutrient cycles revealed that natural lake bottom sediments represent a Pandora's Box of potential water quality problems which man might inadvertently open if municipal sewage discharges or regional sediment loads continue to increase. The results could include a deterioration of water quality and a change in the biological communities of Flathead Lake.

This chapter presents in narrative form these and other major findings of the aquatic research conducted through the Flathead River Basin Environmental Impact Study. Subchapters on river ecology, lake ecology, and fisheries describe the operation of the ecosystem, with emphasis on factors controlling water quality and biological communities. The discussion also includes researchers' suggestions on ways to monitor the aquatic system so that adverse trends can be detected before irreparable damage occurs. The

Yellow Bay & Flathead Lake from east shore, photo courtesy Jack A. Stanford

final subchapter, titled "Land-Water Interface", analyzes how land-use activities are affecting the aquatic environment.

The information generated through the Flathead River Basin Environmental Impact Study will help resource managers and the public evaluate how policy decisions will affect critical components of the aquatic ecosystem. In providing this information, the research should also serve as a necessary first step in charting a course toward long-term conservation of the Flathead system.

ECOLOGY OF THE FLATHEAD RIVER SYSTEM

Physical and Chemical Conditions

The upper Flathead River is the product of the abundant precipitation that collects in the mountainous north and east sides of the basin, where the mountain slopes annually receive 80 to 120 inches of water. Most of the rainwater and snowmelt percolates into the soil, emerging as a multitude of springs and seeps where the groundwater flow contacts the earth surface. In some sites, water from melting snow banks flows overland, forming tiny creeks through alpine meadows. Headwater flows unaugmented by tributaries are defined as 1st order streams.

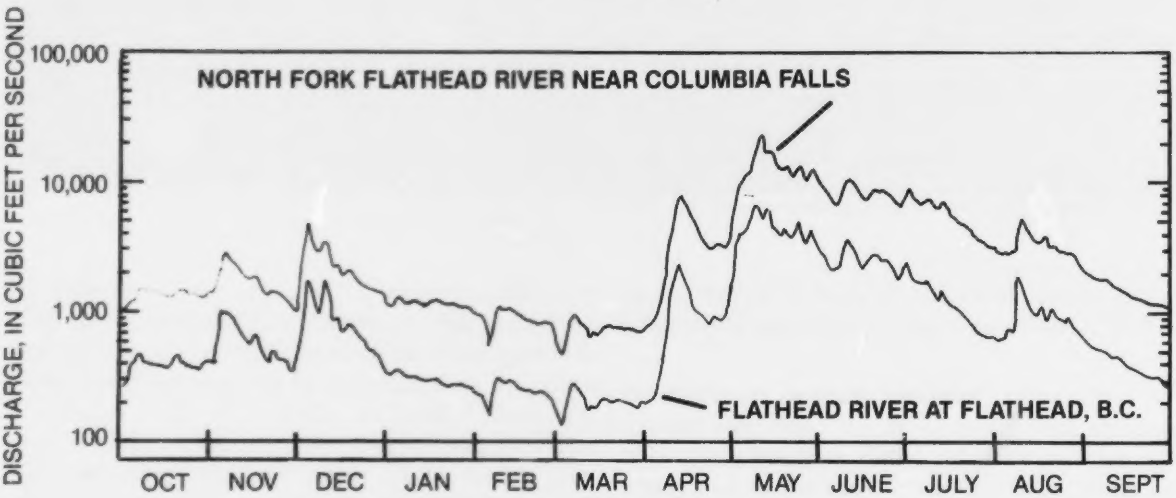
As gravity draws the waters downslope, the small 1st order channels merge to form 2nd order streams. These, in turn, collect other feeders, with the merger of two 2nd order streams yielding a 3rd order stream. This stepwise process creates a progressively smaller number of larger, higher order streams along the elevational gradient. The large tributaries to the North, Middle, and South forks are 4th order streams, while the Swan River and the three forks of the Flathead are 5th order streams or rivers. The mainstem Flathead River is the sole 6th order river in the basin, representing the combined flow of hundreds of headwater creeks funneled from the glacial cirques to the valley floors.

The North, South, and Middle forks contribute over 90% of the flow of the upper Flathead River; the Stillwater and Whitefish rivers are the most important tributaries downstream from where the three forks merge. The annual flow of the upper Flathead River averages 7.6 million acre-feet. The Swan River contributes another 880,000 acre-feet of water directly to Flathead Lake at Bigfork. (See page 24 for detailed flow volume figures for the Flathead River system.)

Flow Regime

The annual flow regime of the Flathead River system strongly influences water quality and the biological communities of both the river and the lake. A hydrograph of the North Fork (Fig. 5.1) illustrates the pattern of seasonal variation in flow volume typical of most Flathead rivers and streams.

FIGURE 5.1



Hydrographs of steam discharge at streamflow stations, 1976 water year.

Source: U.S.G.S.

Streamflows are at their lowest levels at the beginning of the calendar year when cold weather has halted snowmelt and has frozen some surface waters. Groundwater, insulated from the sub-freezing winter air temperatures, continues to feed the streams; this relatively stable groundwater discharge constitutes the minimum, or "base flow", volume of Flathead streams.

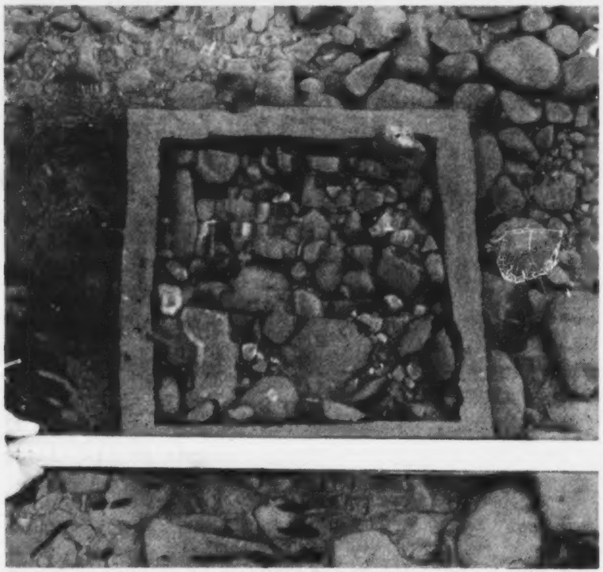
Moderating air temperatures in spring begin to melt the accumulated winter snows and increase streamflows. Most of the meltwater percolates into the groundwater and is then discharged into surface streams; overland flow of snowmelt runoff contributes only a small percentage of stream volume in the Flathead drainage.

Warm weather, often coupled with periods of rain, initiates the surge of spring runoff. Stream levels can rise very rapidly from April through mid-May, and peak flows often exceed 10 times the average flow. During 1964, heavy rains on top of an above-normal snowpack brought record flows to the North and Middle forks and the mainstem Flathead River, and caused extensive flooding in the upper Flathead River Valley. Flows on the Middle Fork rose to nearly 50 times their annual average.

High flows generally persist for four to six weeks, and runoff begins to taper off by mid-June. Streamflows drop steadily through summer as the high elevation snowpack shrinks and the resultant groundwater flow into the tributaries is reduced. Occasional autumn rains send pulses of water through the river system, but base-flow conditions are generally re-established in October and persist through winter.

Substrates and Sediments

Stream substrates in the Flathead River system consist of an aggregation of fine sediments, sand, gravel, cobbles, and boulders. Streams with steep gradients, including most of the mountain tributaries, have a predominance of boulders and cobbles in the substrate because most of the fine sediments are carried downstream by the strong current. Streams with more gentle



Sediments on bottom of river at North Fork Border site, March 1983, photo courtesy Jack A. Stanford

gradients exhibit higher percentages of gravel, sand, and fine sediments.

Streambed materials in the valley rivers are sorted by the flow velocities in different river sections. Fine sediments are deposited primarily in the pools and relatively calm shoreline sites, gravels and cobbles are dominant beneath smooth-flowing runs, and the larger cobbles and boulders are heavy enough to remain in the riffle areas. This sorting, however, is incomplete, and any given stream area will contain a mix of substrate sizes.

High stream flows during spring move tremendous amounts of substrate materials. During normal high-water conditions, materials as large as six-inch cobbles are rolled downstream along the river bottom. This phenomenon, termed bedload movement, prevents deep accumulations of sediments and other fine materials on the river substrate. Redeposition of the bedload plays a major role in shaping channels, islands, and other aspects of river configuration.

The 5th and 6th order rivers in the Flathead Basin have meandered extensively across the valley bottoms during recent geologic history. These channel movements have deposited smooth cobbles and gravels in deep beds which extend up to several hundred yards inland from the present-day river channels. The flood plain region with these loosely compacted cobbles and gravels saturated by groundwater, forms the hyporheic zone. The perpetually dark hyporheic zone is an important habitat for many species of aquatic insects.

Suspended solids, a measure of the amount of sediment carried in the current, average only one to two milligrams per liter (mg/1) during base-flow conditions in most Flathead waters. This concentration is indicative of extremely clear water. Although sediment concentrations in the mountain tributaries increase slightly during spring runnoff, most of the smaller streams remain clear through the high-water period.

Spring runoff, however, has dramatic effects on water clarity in the larger rivers. As the water levels rise, the flows begin to undercut the beds of fine tertiary sediments which line sections of the North Fork, the Middle Fork, and some of their larger 4th order tributaries. A milky color appears after the first spring rains or the initial pulse of snowmelt raise streamborne sediment loads to about 10 mg/1. Continued snowmelt and rainfall increase both the height and the force of the flowing water, and bank erosion accelerates. Sheets of silt- and clay-sized particles drop into the river channels from the steep banks, which in some locations reach altitudes of several hundred feet. The sediments, too fine to settle to the river bottom, are carried in the downstream flow to the Flathead River and eventually to Flathead Lake. Suspended solid concentrations in the Flathead River and its forks can exceed 1,000 mg/1, the equivalent of about one pound of sediment per 100 gallons of water.

Mass wasting caused by river erosion near border on North Fork, photo courtesy Jack A. Stanford

Water Temperature

Flathead streams display a predictable annual temperature regime dictated by the seasonal patterns of air temperatures and flow volumes. Minimum water temperatures occur during winter, when frigid air cools most flowing waters to near the freezing mark. During prolonged periods of sub-freezing weather, ice shelves form along the relatively calm stream edges, but the turbulent midstream flow mixes the water and keeps the temperature at about 32°. Radiational cooling during extremely cold, clear nights can lead to the formation of slush ice or solid anchor ice on the stream bottom.

Near-freezing water temperatures persist in the rivers until air temperatures moderate in late March. During early spring, water temperatures rise steadily, attaining average readings above 40° within a few weeks. The cold snowmelt waters of spring runoff, coupled with the increased stream volume, temporarily slow the temperature rise in the rivers. Lower streamflows and warmer weather through summer, however, bring a second pulse of rapid warming to Flathead streams. Water temperatures peak in late July or early August, and daily maximum readings in the rivers reach about 65°.

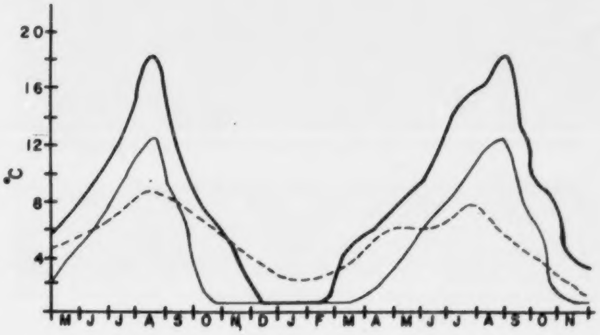
The low flows of autumn allow the streams to be rapidly cooled as the air temperatures drop. This cooling trend continues until waters stabilize at 32° in mid-December.

The temperature regime in high elevation tributaries generally follows the pattern described for the valley rivers, but the average water temperatures are cooler, reflecting the lower air temperatures of the high elevations. Tributaries can reach near freezing temperatures by early November and remain at 32° into early April. Warm-season temperatures in the tributaries are strongly influenced by the amount of shading provided by the stream canopy. Removal of canopy cover, either by natural events or land-use activities, allows more direct solar radiation to reach the stream and can raise stream temperatures considerably.

Spring-fed waters, which include the majority of 1st order streams in the Flathead drainage, are an exception to the pattern of seasonal temperature variation. These streams flow directly from groundwater sources, which are insulated from the ambient air temperatures; as a result, most headwater flows maintain water temperatures near 45°. With increasing downstream distance from the groundwater source, air temperatures begin to control stream temperatures and the pattern of seasonal variation in water temperature is fully established in 2nd order tributaries (Fig. 5.2).

FIGURE 5.2

Annual Temperatures — Three Generalized River Habitats, Flathead River Drainage



Mainstream rivers (bold line), 3rd and 4th order tributaries (excluding lake outlet streams) (fine line), and headwater springbrooks (broken line).

Water Chemistry

The chemical composition of the water plays an important role in determining the kinds and amounts of living organisms which aquatic systems can support. Streams with very high concentrations of dissolved minerals and nutrients often support abundant life; however, highly productive conditions can result in large amounts of decaying plant and animal matter, high levels of bacterial activity, low dissolved oxygen concentrations, and thus poor water quality. Conversely, in streams where nutrients and minerals are limited, the production of living matter is low, but water quality remains excellent. The clear, clean waters of the Flathead River and its tributaries typify a stream system with low productivity for aquatic life and excellent water quality.

The concentration of minerals (dissolved solids) in Flathead waters is dictated by the geology of each individual stream drainage basin. Some of the tributary watersheds are underlain by Precambian bedrock, comprising argillites (siltstones), quartzites, and limestones dating from more than 600 million years ago. These geologic types are resistant to weathering and endow streams with very low concentrations of dissolved solids. "Younger" limestone formations, dating from 200 to 600 million years ago, are more readily dis-

dissolved by precipitation, streamflow, and groundwater, and thus confer greater concentrations of dissolved solids to streams.

The mineral constituents of the soils and rocks enter solution in the form of electrically charged atoms or groups of atoms called ions. Calcium constitutes about 70% of the positively charged ions in Flathead waters, reflecting the dominance of limestone (calcium carbonate) formations in many of the high elevation watersheds. Calcium is an important mineral for biological activity, and the ability of streams to support plants and animals has been correlated with the concentration of calcium ions in the water. Magnesium ions, derived from dolomitic limestone, make up most of the remainder of the positive ions, and only very small concentrations of dissolved sodium and potassium are present.

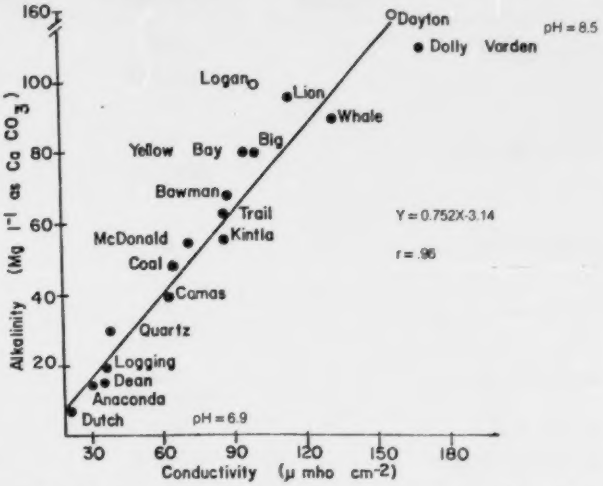
The dominant negative ion in solution is bicarbonate, which is produced from the carbonate ions dissolved from limestone and through chemical reactions involving carbon dioxide gas and water. In high enough concentrations, bicarbonate solutions have the ability to neutralize acids. This natural "buffer system" can provide short-term protection to the aquatic ecosystem from some types of pollution, such as acid precipitation or the acidic waters which often drain from mining operations. Poorly buffered waters, on the other hand, may prove highly susceptible to acidification, as shown by recent reports that stream ecosystems in the Colorado portion of the Rocky Mountains are experiencing damage from acid precipitation.

Buffering capacities, measured as alkalinity, exhibit a wide range of values in Flathead streams (Fig. 5.3). Dutch Creek on the west slope of Glacier National Park has the lowest measured alkalinity and has been described chemically as little more than flowing distilled water. Dolly Varden Creek is at the other extreme in terms of natural buffering capacitiy for Flathead Basin streams. In general, Flathead streams rank relatively low in dissolved solid concentrations compared to other North American waters.

The distribution of buffering capacity in Flathead streams displays some dramatic geographic contrasts, reflecting the abrupt shifts in bedrock geology. On the east side of the North Fork Valley, streams draining the Precambrian rocks of Glacier National Park have very low ion concentrations, while waters flowing from the limestone formations on the west side of the valley exhibit moderate levels of calcium and bicarbonate ions. Dolly Varden Creek, a Middle Fork tributary which drains the soluble limestones composing the northeast face of Elk Ridge in the Flathead Range, has the highest natural buffering capacity measured of any flowing water in the basin; Dean Creek, a South Fork tributary which drains the argillite outcrops on the southwest slope of the same ridge, is among the least well buffered streams.

FIGURE 5.3

Relationship Between Total Alkalinity and Conductivity Based Upon Field Data Collected Winter and Spring 1979, 1980



The chemical characteristics of the three forks of the Flathead and the main Flathead River represent a composite of the inflowing waters. The result is moderate dissolved solid concentrations, dominated by calcium and magnesium positive ions and a carbonate-bicarbonate system of negatively charged ions. These larger rivers are slightly alkaline and display a stable, moderate buffering capacity (Table 5.1).

Dissolved solids, including calcium, bicarbonate, and other common ions, decrease in concentration during runoff. The dilution of ion concentrations reflects the inflow of rainwater and snowmelt which have little time to dissolve minerals from the soils and rocks before entering the streams.

Phosphorus, a key nutrient for plant growth, occurs in very low concentrations throughout Flathead streams during base-flow conditions. Concentrations are generally in the range of 5 to 15 micrograms per liter, equivalent to one part phosphorus for every 60 million to 200 million parts of water. Although the sedimentary bedrock which underlies the Flathead drainage contains significant amounts of phosphorus, most of the phosphorus is tightly complexed with iron and other mineral constituents and does not dissolve to enter the stream system.

TABLE 5.1

Physicochemistry of riverine environments at selected locations in the Flathead River system. Data are means with ranges in parenthesis.

Site	Stream Order	Conductivity (umhos/cm^2)	Dissolved Organic Matter (mg/1)	Total Phosphorus (ug/1-P)	Nitrate (ug/1-N)	Sulfate (mg/1-S)
Roy's Creek	1	150 (138-160)	.48 (.26-.68)	12.4 (9.8-12.)	361 (271-497)	1.0 (.66-1.2)
Yellow Bay Cr.	2	95 (83-111)	.72 (.31-.24)	11.3 (7.9-26)	27.1 (13.5-45)	.53 (.32-.66)
Dutch Creek	4	22 (17-23)	3.4 (1.3-6.5)	—	38 (22-67)	.80 (.73-.90)
Trail Creek	4	94 (68-134)	.81 (.03-3.4)	12.3 (3.6-45.)	90 (45-450)	3.8 (1.6-9.3)
Kintla Creek	4	85 (960-108)	.77 (.33-2.2)	5.7 (2.8-17)	36 (13-58)	.66 (.33-.86)
North Fork at Camas Creek	5	160 (90-274)	1.2 (.34-3.12)	18.0 (.7-146)	45.5 (3-162)	1.3 (.27-3.6)
Middle Fork at West Glacier	5	144 (91-228)	.78 (.04-2.9)	26.5 (1.3-293)	112. (32-212)	1.0 (.27-2.8)
Mainstream at Sportsman Bridge	6	146 (94-183)	1.3 (.3-2.9)	19.6 (3-1.37)	70.0 (20-140)	.68 (.1-1.8)

During spring runoff, phosphorus concentrations in the rivers rise sharply as phosphorus-containing silt- and clay-sized particles are eroded from the steep, unconsolidated sediment banks bordering the forks of the Flathead River (Fig. 5.4). Again, most of this phosphorus is bound to the mineral constituents of the sediment particles and does not enter solution to stimulate plant growth.

Phosphate ions, a form of phosphorus which can readily be used by plants, exist adsorbed to (attached to the surface of) the fine sediments carried during runoff. Some exchange of phosphate ions between the sediments and the water may occur during downstream sediment transport, but this aspect of phosphorus dynamics is not well understood. Where fine sediments settle to the river bottom during low flows, algae will colonize these sediments, indicating that some of the phosphate ions can be extracted biologically to stimulate growth by plants. Most of the phosphorus-containing silt and clay sediments, however, are too small to be deposited on the stream bottom during high water. These sediments are carried to Flathead Lake where, as discussed in the following subchapter, about 6% of the total phosphorus carried by the sediment particles is available for use by algae.

Research is ongoing at the University of Montana Biological Station to resolve the complexities of the sediment-phosphorus-plant productivity relationships. In general, however, researchers do know that very little of the sediment-carried phosphorus is available to stimulate the growth of algae in the rivers of the Flathead drainage.

Concentrations of nitrogen, another important plant-growth nutrient, are also relatively low in the Flathead River system, although the nitrogen supply to algae is not nearly as limited as the supply of phosphorus. Nitrogen compounds enter the water from decomposing plant and animal materials in the stream and on the surrounding land (Table 5.2).

Organic carbon, also derived from plant and animal materials, exists in both particulate and dissolved forms in the stream system. Particulate organic carbon, which reflects the amount of instream plant productivity, occurs in low concentrations in Flathead streams. Spring runoff flows contain increased concentrations of particulate carbon because the high water recruits vegetative litter from the stream banks into the stream channels and because sediments in the water scour algae from the underwater rocks. Particulate organic carbon serves as the primary food for many species of aquatic insects.

FIGURE 5.4

Relationship of suspended-sediment concentration and total phosphorus for Flathead River at Flathead, B.C., for period of record. Breaks in line represent periods of no data.

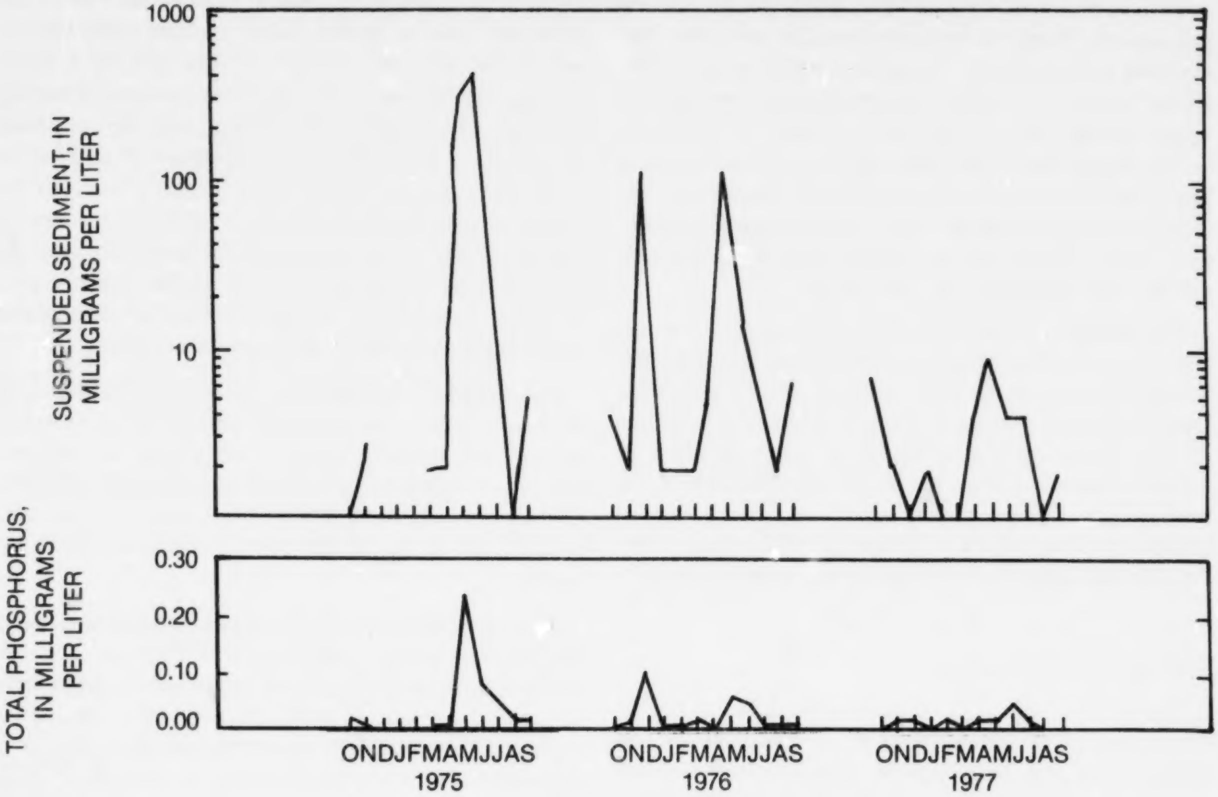


TABLE 5.2

Comparative Mass of Carbon Forms and Nitrogen (Means) in Bottom Sediments (Fines 500 um) Collected in Trays at Various Locations Along The Flathead River Continuum.

Site	Stream Order	TOC*	TOC**	C:N***
Roy's Creek	1	38.8	99.1	20.1
Yellow Bay Creek	2	11.6	89.2	19.4
Trail Creek	4	47.7	99.8	16.4
North Fork @ Border	5	17.7	52.2	22.8
North Fork @ Camas Creek	5	9.6	77.0	20.9
Middle Fork @ West Glacier	5	4.9	62.6	18.1
Mainstream @ Presentine Bar	6	17.2	90.2	14.1

*Total Organic Carbon (g/m^2)
**Organic Carbon/Total Carbon
***Total Carbon/Total Nitrogen

Dissolved organic carbon, which constitutes about 80% of the organic carbon load in Flathead streams, results primarily from the inflow of groundwater. As groundwater percolates through the soil, it dissolves carbon compounds from the leaf litter and the surface soil layers; these carbon compounds are later discharged into the stream by groundwater springs. Dissolved organic carbon concentrations rise during spring runoff, because of the high rates of rainwater and snowmelt percolation into the soil and the resultant high discharge of groundwater into the stream system. Organic compounds dissolve rapidly through contact with water, unlike the very slowly dissolving mineral constituents of the soil and bedrock.

The limited amount of decomposing plant material, the cool water temperatures, and the characteristic stream turbulence all help maintain high concentrations of dissolved oxygen. Oxygen saturation is an important requisite for supporting many species of aquatic insects and the coldwater-adapted fish of the trout family. High oxygen levels also allow microorganisms to metabolize (break down) organic compounds and thus purify the stream of waste materials.

Plant Productivity

The plant community in the Flathead River and its tributaries is dominated by algae attached to the stream substrate. Microscopic, single-celled diatoms and both single-celled and filamentous (multi-celled) green algae account for most of the living plant tissue. The diatoms compose the thin, brownish film which gives a slippery coating to the surface of underwater rocks, while during low-water periods the multi-celled algae are often apparent on the stream substrate as green patches with long filaments streaming in the current.

Plants obtain their energy through exposure to sunlight and, in turn, produce the energy that drives biological communities. The green chloroplasts within the plants use solar radiation to drive photosynthesis, the process which converts carbon dioxide gas and water into carbohydrates. Some carbohydrates, including sugars and starches, are used to meet plants' energy needs, while other compounds are modified to serve structural purposes or to participate in cellular processes. The production of energy-containing compounds through photosynthesis by plants is termed "primary productivity" because this process represents the initial method through which energy is incorporated into living tissue.

Organisms lacking the photosynthetic ability of plants obtain energy by consuming plant materials or eating animals which depend on plant production. The sequential transfer of energy between organisms forms a food chain. A typical food chain within the Flathead River ecosystem might include diatoms converting sunlight into organic matter, mayfly nymphs grazing on diatoms, cutthroat trout feeding on mayfly nymphs, and a bald eagle eating trout. Aquatic food chains can also be based on vegetation produced on land; for example, willow leaves which fall into the stream are colonized by bacteria, which are eaten by stoneflies, which in turn might be eaten by fish. As illustrated by the food chain examples, energy produced in, or added to, the stream ecosystem by plants controls the dependent animal communities.

Measurements taken throughout the Flathead River system revealed very low levels of primary productivity (i.e., low energy production by plants) in comparison to most other river systems in temperate climates. Researchers attribute this low productivity to the natural shortage of phosphorus, a critical plant-growth nutrient.

Natural disturbance of the stream bottom also keeps the amount of plant material low in Flathead streams. Sediments carried by spring runoff scour algae from exposed rock surfaces while, during winter, patches of anchor ice scrape the stream substrate. The removal of attached algae through abrasion prevents the buildup of large amounts of plant material; thus, the standing crop of organic material to support higher levels in the food chain, including aquatic insects and fish, is consistently low in the Flathead drainage.

Researchers noted a general trend toward lower primary production with a reduction in stream size. The narrow tributaries are subject to more shading by streamside vegetation, and water temperatures are generally cooler in the high elevation waters than in downstream rivers. Both of these factors contribute to the reduced rate of photosynthesis by algae in the smaller streams. Additionally, nutrient supplies are lower in most headwater streams than in the larger rivers, which cut through deposits of phosphorus-containing fine sediments.

The highest primary production by aquatic plants in the Flathead River system occurs prior to spring runoff and again during autumn. These periods are characterized by moderate temperatures and low, clear water, which allows ample light to reach the river bottom.

Jon Jaurdonais measures metals concentrations on atomic absorption spectrophotometer in Freshwater Research Lab at UMBS.

Organic compounds of terrestrial (land) origin provide a significant amount of energy to the stream ecosystem. Autumn leaf fall adds the largest single dose of terrestrial carbon compounds, especially along small tributaries where deciduous trees and shrubs line the stream banks. Spring runoff washes vegetative litter and decaying animal matter from the flood plains into the stream channels. During the remainder of the year, terrestrial sources make a minor but steady contribution to the streamborne energy load, with components of this dry fallout including pollen, leaves and branches, flying insects, and occasional dead vertebrates.

The amount of biologically usable energy entering the Flathead River system from the land has not been quantified because extreme local variations make it almost impossible to obtain representative samples. The terrestrial energy contribution is, however, known to be extremely important to the aquatic community, as reviewed in the ensuing discussion of the aquatic insects.

Aquatic Insects

To the streamside observer, the clear waters of Flathead streams serve as a flowing lens, alternatively bringing in and out of focus the multi-colored, multi-textured, and apparently lifeless streambottom. Within this matrix of sand, gravel, and cobble, however, is a carefully concealed array of grazers, predators, and scavengers, collectively known as the aquatic insect community.

More than 300 species of aquatic insects have been identified in the upper Flathead River system, and possibly several hundred more remain to be catalogued. This diversity is exceptional for a single drainage, and reflects the intricate adaptations through which different insect species partition food, space, and even time resources.

The aquatic insect community in the Flathead River system challenges ecologists to determine how so many species can coexist in the stream environment. But beyond this academic question, the aquatic insect community plays two roles vital to the aquatic ecosystem. First, aquatic insects serve as a key energy link by "packaging" organic carbon compounds to sustain the fish populations of Flathead waters. Second, aquatic insect populations provide a way to monitor the health of the stream ecosystem so that environmental alterations can be detected and perhaps remedied before irreversible damage occurs.

The research conducted through the Flathead River Basin Environmental Impact Study represents a rare attempt to document the community organization, life cycles, and energy relations of aquatic insects on a drainage-wide basis. The highlights of this effort, as presented here, indicate the importance of the aquatic insect community to the functioning of the Flathead aquatic ecosystem.

Major Groups of Aquatic Insects

Caddisflies, mayflies, stoneflies and midges are the most important groups of aquatic insects within the Flathead River system, collectively dominating measurements of biomass, diversity, and population. Individuals of these groups of insects have an aquatic existence only during the immature stages of their life cycles; upon colmpletion of the maturation process, which ranges from several months to several years, caddisflies, mayflies, stoneflies and midges change into winged adults and emerge from the water. The adult forms generally live only a few days or weeks, and many do not feed. After the adults mate, the females return to the water, lay their eggs, and die.

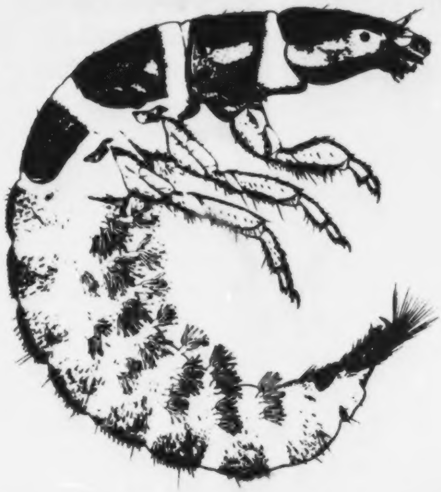
Caddisflies exist in a wormlike larval form during their underwater development (Fig. 5.5). Caddis larvae generally pass through five growth stages, or instars (Fig. 5.6), and fully grown larvae in the Flathead drainage range from one-eighth of an inch to about one-and-one-half inches long, depending on the species. Caddis larvae are generally omnivorous, feeding on algae, tiny aquatic insects, and organic detritus composed of decaying plant and animal tissue. Well over a hundred species of caddis are believed to inhabit Flathead waters, although a study of lakes and ponds has yet to be completed.

Larvae of different species of caddisfly pursue one of three distinct life history strategies during their benthic (stream bottom) existence. Case-building caddis larvae construct a protective enclosure of sand, small stones, or sticks. The cases, each characteristic of a particular species, range from simple tubes to bulky stick lodges to elaborate spiral formations. As they search for food, crawling larvae drag these "mobile homes" across the stream bottom. These cases also provide needed ballast, allowing the larvae to move in the river current without being swept downstream.

Net-spinning caddis larvae weave fine-meshed silk nets in the small spaces between underwater stones, sticks, or other objects. These nets, resembling submerged spiderwebs, filter fine particles from the current. Periodically, the caddis larva leaves the security of its permanent retreat and feeds on the microscopic food particles collected in the net.

North Fork Border, March 1983, photo courtesy Jack A. Stanford

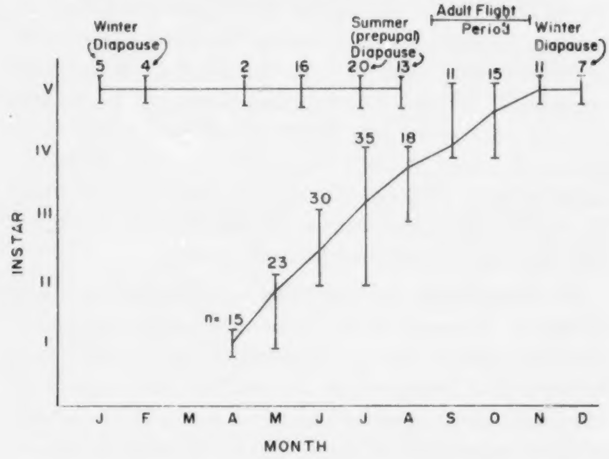
FIGURE 5.5
Hydropsychidae: Arctopsyche



The caddis *Arctopsyche grandis*, a common net-spinning resident in the 3rd and 4th order segments of the Flathead River system.

Life cycles of *Dicosmoecus gilvipes* Caddisfly in the Flathead River Basin, Montana. Larval instars (I-V), diapause and adult flight period are indicated. The small horizontal lines indicate the range of instars found each month among the 2-year classes. Modes have been joined to show periods of growth.

FIGURE 5.6
Representative Caddisfly Life History



A third group of caddis larvae has a free-living existence. These species swim in the current or crawl along the substrate or vegetation to capture animal prey or to feed on plants and fine detrital material.

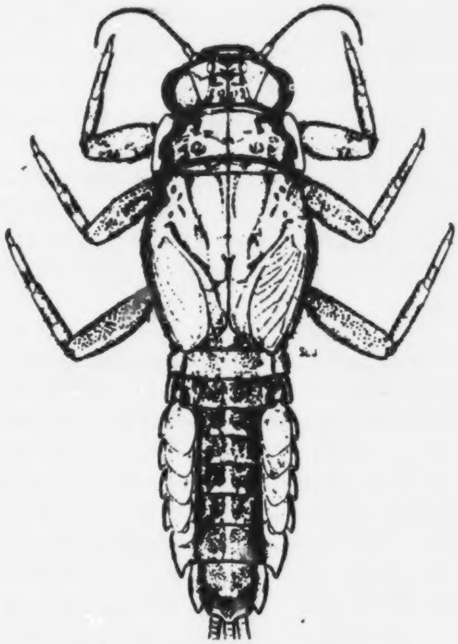
The pupal phase of the caddis life cycle marks the transition between the immature aquatic form and the terrestrial adult. Upon completion of the larval phase, caddis enter sealed cases, or pupation chambers, which are cemented to the stream substrate. Within these shelters, the larva develops an exterior husk (the pupal shell) and, through a two- or four-week period, metamorphosize into a winged adult. Adults emerge by cutting their way out of the pupation chamber and rising to the surface or crawling to the water's edge. Swarms of the mothlike adult caddisflies are common sights over flowing waters throughout the warm season. Following mating, females return to the water to lay their eggs.

Most caddis have a one-year life cycle from egg to reproducing adult. Exceptions include some species with two generations per year and a few species displaying a two-year life cycle.

The more than 70 species of mayflies (Fig. 5.7) identified in the upper Flathead River system are primarily herbivorous and feed by grazing on algae. Mayflies exhibit a similar size range to caddisflies and, like caddis, most species have a single generation per year.

FIGURE 5.7

The mayfly, *Ephemerella inermis*, a common species found under rocks in the 5th and 6th order segments of the Flathead Rivers



The varied forms of mayfly nymphs reflect a range of habitat preferences and behavioral adaptions. Flat-bodied nymphs, or clingers, are found attached to rocks in many of the swiftest stream sections. The low profile of these species helps them take advantage of the 2-millimeter-thick zone of nonturbulent water on the surface of underwater rocks. Clinging nymphs feed by scraping up the algae and diatoms that coat exposed rock surfaces. Burrowing mayfly nymphs display an elongated body with tusked mandibles for digging through silt deposits. These species inhabit U-shaped burrows, drawing a stream of oxygenated water and food particles by the fanning action of their gills. The swimmers are the most mobile of the mayfly nymphs, with a streamlined, fish-like shape and the ability to dart through swift water. Crawling mayfly nymphs, the last of the four general types, have a broad, bulky shape. These nymphs inhabit a wide range of current speeds and feed by crawling along the stream bottom in search of algae or organic detritus.

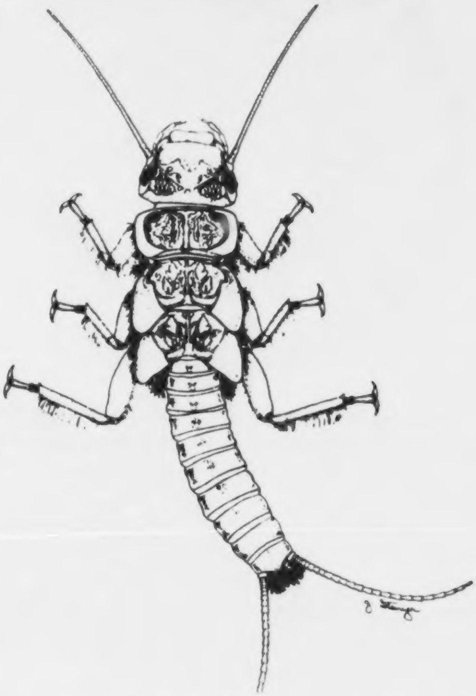
Mayfly nymphs molt many times during their development, but do not enter a pupal stage. After the final molt, intricately folded wings develop beneath the nymphal wing pads. At maturity, the nymph rises to the stream surface, the exterior shell splits, and the adult emerges. During a concentrated emergence, hundreds of adult mayflies can be observed gliding on the surface currents, with their narrow bodies and upright wings resembling miniature sailboats. Often fish will take advantage of such a mayfly "hatch" and feed on the nymphs or adults as they drift in the current.

The nymphs of most of the more than one hundred stonefly species reach maximum abundance amidst the gravel and cobble underlying stream riffles. Some stoneflies live along wave-washed, stony lakeshores, while others inhabit the perpetually dark, saturated region of the flood plain below or lateral to the river channel.

Stonefly nymphs, the largest aquatic insects in the Flathead drainage, range up to 2½ inches in length (Fig. 5.8). Although stoneflies exhibit a generally consistent form, different species have widely divergent methods for obtaining food. The largest stoneflies feed by shredding leaves deposited in the water by streamside vegetation. Some stonefly nymphs are predatory, others graze on algae, while still others feed exclusively on fine organic debris. The largest number of stonefly species are "opportunivores" and feed on living and dead plant and animal tissue.

FIGURE 5.8

**The stonefly *Claassenia sabulosa*
a common species in the 5th and 6th order
segments of the Flathead River**



Like mayflies, stonefly nymphs molt repeatedly as they grow, with most species experiencing from 10 to 20 instars. The last instar has two well developed sets of wings beneath the wing pads. In preparation for emergence, the nymph crawls across the stream bottom to the shore and climbs up on the bank or streamside vegetation. There, the nymphal shuck splits and the winged adult emerges. Adult stoneflies emerge from February through mid-September in the Flathead River system. Five species exist in the nymphal stage for two to four years before emergence of the adults; the remainder have one-year life cycles.

Midges include the many tiny aquatic species which belong to the same insect order as houseflies and mosquitoes. Midge larvae, generally shorter than one-quarter inch, can occur in densities up to tens of thousands per square meter in silt bottoms or on submerged vegetation. Midges commonly exhibit several generations per year. Although midges are important components of clean water insect communities, many species are extremely tolerant of polluted, poorly oxygenated waters, where caddisflies, mayflies, and stoneflies are unable to survive.

The movement of insects downstream in the current is termed "drift". One aspect of drift comprises the assemblage of insects accidentally dislodged from the stream substrate by the force of the moving water. Most insects are able to regain their hold on the substrate in a matter of seconds and are thus moved only a few yards downstream. Behavioral drift refers to the intentional entry of aquatic insects into the stream current. Many kinds of mayfly nymphs and some species of caddisfly larvae and stonefly nymphs jettison themselves from the stream bottom and float freely downstream on an almost daily basis during the warm season. Behavioral drift allows aquatic insects to move quickly to potential new food sources and away from areas of high populations and excessive competition. Catastrophic drift is the mass downstream exodus of aquatic insects in response to adverse environmental conditions, such as high-water, ice scouring of the stream bottom, high temperatures, or pollutants.

Over time, accidential, behavioral, and catastrophic drift would cause a progressive downstream movement of all aquatic insect populations. This trend is countered by upstream, egg-laying flights of most aquatic insect species. Additionally, many nymphs and larvae continually work their way upstream during normal foraging activities.

Aquatic Insect Energetics

The amount of aquatic insects in the Flathead River system is very low. Typically, the weight of live insects (the insect biomass) contained in benthic samples from Flathead streams is on the order of 10 times smaller than samples taken from other North American river systems. The low biomass is related to the limited amount of energy available which, in turn, is a function of the low primary productivity by algae in the stream system.

Terrestrial sources provide most of the energy that drives the aquatic insect communities in headwater streams. Each fall, cottonwood, aspen, birch, willow, alder, and other deciduous trees and shrubs drop millions of leaves into the stream channel. These leaves collect in tight packets between rocks in riffle areas or settle to the bottoms of the deeper pools.

Unlike woody tissues and conifer needles which have little food value, deciduous leaves can be used by many bacteria, fungi, and single-celled protozoans, which derive energy and nutrients by decomposing plant tissue. Several species of stonefly and caddis feed on the deciduous leaves, using well-adapted mandibles to shred them into fine particles which can be swallowed. These aquatic insects, or shredders, also derive a considerable part of their food energy by ingesting the thin film of microorganisms which coat the leaf tissue.

Leaf particles ground into smaller particles by aquatic insects or broken apart by the mechanical action of water flow, ice, or substrate movement enter the stream current. Residual particles larger than one millimeter across are termed coarse particulate organic matter (CPOM) and dominate the suspended particle drift of headwater streams. The larger net-spinning caddis larvae trap some of these particles, while other particles settle to the stream bottom to be eaten by a host of mayfly and stonefly nymphs, along with midge and caddis larvae.

As tributaries merge into ever-wider streams, several factors operate to reduce the size of organic particles available to aquatic insects. First, the increased stream width opens the forest canopy; this reduces the role of leaf fallout as a source of large organic particles to the stream. Additionally, the coarse particles generated in upstream sections have undergone reduction in size due to physical events and biological processing during the downstream flow. Finally, more sunlight reaches the stream surface because of the open canopy. This enhances primary productivity and increases the populations of algae and diatom cells, which contribute to the load of fine particulate matter carried by the stream.

Benthic insect communities in the larger (higher order) streams are adapted to take advantage of the smaller particles which dominate the supply of organic matter. Collectors and filter feeders, such as the net-spinning caddis larvae and the burrowing mayfly nymphs, become more abundant by virtue of their ability to capture and use small particles. Species of mayflies and cased caddis which glean fine organic particles from the stream bottom or scrape algae from rock surfaces also increase in number.

Primary production through photosynthesis is the most important source of energy in the larger streams and rivers. The biological communities in these waters produce more organic material than they process, in contrast to the small tributaries, where processing of organic matter, largely of terrestrial origin, exceeds the production of plant tissue through photosynthesis.

Throughout the stream system, an important form of energy for aquatic insects is the so-called colloidal organic particulate. This material consists of algae cells

North Fork Flathead River, photo courtesy Jack A. Stanford

and fine organic detritus, the nonliving debris derived from plant tissue, insect parts and feces, and other fine bits of plant and animal matter, all tightly bound to fine sediments on the stream bottom. The energy value of the colloidal particulate is bolstered by colonies of bacteria and other microorganisms, which grow on the organic compounds. Nearly every species of aquatic insect uses the colloidal organic particulate as a primary food source during early development, and some species use this material through their entire life cycle.

Deposition of the fine-particle organic detritus follows an annual cycle. Spring runoff marks the low in substrate detritus, as high water carries away most of the accumulated organic materials and deposits loads of inorganic sediments on the stream bottom. Summer warming stimulates algal growth, and lower flows allow decomposing plant and animal matter to settle to the stream bottom. During fall, primary productivity reaches a maximum and terrestrial leaf litter adds to the load of organic material. The decomposition products of these materials contribute to peak detrital concentration from late fall through early spring, when the early instars of most aquatic insects are experiencing their most rapid growth. Riffle backwash and pool areas are the primary sites for the deposition of fine organic particulate.

Temperature Control of Insect Life Histories

The development of caddisflies, mayflies, and stoneflies is precisely controlled by water temperature, with specific cues triggering the hatching of eggs, the emergence of adults, and other life history events. This genetically programmed response insures that individuals of each species emerge synchronously and develop under optimal environmental conditions and that the emergence of each species is synchronized so mating can occur.

The temperature-controlled maturation process is known as temperature summation, and can be quantified for each species. The large, leaf-shredding stonefly, *Pteronarcella badia*, for example, requires a total of 2,300 to 2,600 degree-days* of water temperature during its one-year life cycle to mature. Generally, this temperature criteria is met, and emergence occurs, within a two-week period from mid- to late June along the main Flathead River near Kalispell. Colder than normal water temperatures, as would be caused by cold spring weather or prolonged snowmelt runoff, shift emergence to the later part of this interval; warmer water temperatures often experienced during low-water years, induce emergence at an earler date. At higher elevations along a stream course, the cooler temperatures cause adults to emerge later than in warmer downstream reaches. *P. badia* nymphs were found to emerge about a week earlier near Kalispell than at a site along the Middle Fork 30 miles upstream.

Temperature cues also influence other stages of aquatic insect life cycles. Many stoneflies and mayflies experience an inactive stage in which the development of eggs or early nymphal instars ceases until water temperatures change. For some species, this diapause occurs in summer, to be broken when water temperatures cool in the fall; other species have a winter diapause, and development resumes during spring.

Air temperatures, as expressed in shoreline water temperatures, provide the final cue for the transformation of most aquatic insect species into adults. Just prior to emergence, the nymphs and larvae move into shallow waters along the stream edge. Unlike the deeper, swifter mid-stream flow which resists rapid temperature change, the calm streamside zone closely reflects surrounding air temperatures. When the air temperature and thus the ambient water temperature reach the proper level, the adults emerge.

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*Degree-days are determined by adding up the average daily water temperature (in degrees C) over each day from egg deposition to adult emergence. A day with an average water temperature of 10°C (50°F) would constitute 10 degree-days; a month averaging the same water temperatures would generate 30 days times 10 degrees, or 300 degree-days.

The precise response of aquatic insects to temperature insures that emergence, egg-laying, early development, and other stages of the life cycle occur at the optimal times of the year. On a community basis, temperature summation means that different species of aquatic insects emerge in the same sequence from year to year, even though the emergence calendar may be advanced or retarded in response to annual temperature variations.

Diversity

The Flathead River system hosts an exceptionally diverse aquatic insect fauna. Nearly three hundred species each of mayflies, caddisflies, and stoneflies are known to inhabit Flathead streams, and the drainage-wide totals could rise significantly as ponds and lakes are surveyed. The 105 kinds of stoneflies collected in the basin constitute almost one-fourth of all stonefly species in North America.

One factor contributing to the insect diversity in the Flathead River system is the change in species composition along the stream gradient. The heat budget required for stoneflies, mayflies, and caddisflies to complete their life cycles limits the range of water temperatures which each species can inhabit. Consequently, most species are restricted to either headwater streams, medium-sized tributaries, or the larger rivers and are replaced by new species with the change in temperature regime that accompanies elevational changes.

Changes in food type and substrate also contribute to shifts in species composition along stream gradients. For example, in the downstream transition from closed-canopy streams to open-canopy rivers, leaf litter declines in importance as a food source while algae becomes more important. This shift in food type favors grazers and other algae-eaters over shredders. Similarly, species adapted to silty substrates occur more commonly in lower reaches than in faster headwater sections where gravel and cobble are dominant.

A second aspect of aquatic insect diversity is the array of species which occur together, as indicated by the 40 kinds of stoneflies and over 30 kinds of caddis collected at a single sampling site on the Flathead River near Kalispell. Researchers have related this remarkable local diversity to the mixture of habitat conditions, or the environmental heterogeneity, that characterizes the Flathead River system. Differences in physical features account for much of the habitat diversity. Even a short stream section often encompasses shallow shoreline areas with slow current, moderate-speed runs, mid-stream riffles, calm backwaters, and slow, deep pools. The underlying substrate might include silt, sand, gravel, cobble, boulders, and aquatic vegetation. Available food can be equally diverse, consisting of living algae, terrestrial plant material, coarse and fine particles of organic detritus, microorganisms, and various invertebrate prey species.

Stoneflies in the Flathead River system display five distinct feeding strategies to divide available food resources, and species within these functional groups are further segregated according to food type and habitat use. Among caddis larvae, the case-builders search the substrate for food, while net-spinners collect organic particles suspended in the current. Additional variations—for example, different mesh size or net location among net-spinners—insure that larvae with similar methods of obtaining food do not compete for identical resources.

Specialized use of the various habitat components by different aquatic insect species, a phenomenon termed "resource partitioning", reduces competition and allows many species to coexist. In less complex environments, on the other hand, the range of food types, substrate composition, current speeds, and other habitat features is reduced. The few best-adapted species are able to dominate the community, and diversity is low.

B. K. Ellis and M. Speis process sediment samples from North Fork, March 1983, photo courtesy Jack A. Stanford

Species-specific responses to temperature also contribute to local aquatic insect diversity. Some species grow and develop during the summer and autumn and experience a resting stage (diapause) when water temperatures drop in winter; other species develop fastest in winter and have a warm season diapause. Within these broad categories, different species display fine-tuned temperature responses to stagger development from one another by weeks or months. Temperature cues thus allow each species to take advantage of food and habitat resources available during a certain time of the year, and avoid competition with other species that may use the same resources at different times.

The most closely related species (which are also those most likely to have similar behavior and habitat requirements) often exhibit such seasonally staggered periods of growth and development. Four coexisting stonefly species belonging to the sub-family *Perlodinae* sequence their emergence at monthly intervals from April through July. This progression of adult emergence indicates staggered development of immature forms; as a result, different size nymphal instars occur on the stream bottom and interspecific competition for food and habitat is reduced. Similarly, four net-spinning caddis species, which frequently occurred on the same submerged boulder, reduce interspecific competition by differences in the timing of larval growth. Species-specific responses to temperature cues mediate this staggered development and thus allow the coexistence of closely related species.

The hyporheic habitat. A unique example of habitat use is exhibited by four stonefly species whose life cycle initially baffled investigators of the Flathead River aquatic insect community. These species *(Paraperla frontalis, Isocapnia missouri, I. crinita,* and *I. grandis)* were commonly collected along the river shoreline just prior to emergence, but no earlier instars could be found despite repeated sampling of the stream bottom. Researchers speculated that early development of these stoneflies occured in the groundwater.

This hypothesis was confimed in 1973 when stonefly nymphs began showing up in the tap water of the town of Eureka, located along the Tobacco River just west of the Flathead Basin. The source of the nymphs, and of local residents considerable discomfiture, was a new municipal water system which tapped the floodplain aquifer 15 feet deep and up to 165 feet inland from the Tobacco River shoreline. The three municipal pumps were drawing both the water and the three-quarter-inch insects from the saturated underground gravels, or hyporheic zone. The stoneflies found in the Tobacco River floodplain groundwater were the same species whose early instars were missing from the Flathead River collections. These early instar nymphs have since been found in groundwater along the Flathead River flood plain near Kalispell.

Filtration solved the Eureka water supply problem, and further research revealed the nature of the hyporheic insect community. In addition to the four kinds of stonefly nymphs, the hyporheic zone supports midges, beetles, leeches, and the early instars of species of mayflies and other stoneflies. Food supply for the insect community consists of organic detritus and algae carried by the groundwater flow, in addition to the aquatic invertebrates themselves, which serve as prey for many of the hyporheic species. Spaces in the loosely compacted flood plain gravels are large enough to permit the insects to move about freely.

The hyporheic community of the Flathead River flood plain has not yet been investigated; however, given the expansive flood plain gravels and the considerable groundwater flow, this community may extend several hundred yards laterally from the channels of the 5th and 6th order rivers. The hyporheic zone, particularly areas directly beneath the stream bottom is believed to provide crucial habitat for the eggs and young instars of many aquatic insect species in the larger rivers of the Flathead system. Little hyporheic habitat exists in the tributaries, which generally have confined channels without adjacent groundwater reservoirs or extensive flood plain gravel deposts.

The Effect of Hungry Horse Dam on the Aquatic Insect Community

The diverse Flathead River aquatic insect community is made possible by a complex, seasonally variable environment. Each insect species displays a distinct pattern of habitat preference, resource use, behavioral adaptation and timing of development which permits coexistence with other species at the same location.

Alterations which simplify the aquatic habitat will eliminate species dependent on the lost habitat components. For example, insect diversity is much lower where soil erosion has blanketed the stream bottom with sediment than in a comparable stream section which hosts a mix of substrate types. Stream channelization and dewatering also remove habitat features and reduce insect diversity.

S. Perry and W. Perry collecting aquatic insects from the bottom of the South Fork of the Flathead River

The effects of habitat alteration on aquatic insect diversity have been extensively documented on the lower South Fork of the Flathead River, where Hungry Horse Dam has caused drastic changes in water temperature, flow volume, substrate composition, and food supply. These changes have simplified the aquatic environment and transformed a diverse insect community into one dominated by a very few species. The influence of the dam also extends downstream to the main Flathead River below its confluence with the South Fork. A review of the dam impacts indicates the fragile nature of the Flathead River aquatic insect community and sheds light on the potential of other man-caused disturbances to alter the finely balanced aquatic insect community.

Environmental conditions on the lower South Fork. Completed in 1953, the 50-story-high Hungry Horse Dam is operated by the federal Bureau of Reclamation to help meet the peak power demands of the Pacific Northwest. Power production reaches a maximum of 320 megawatts when flow releases of 11,500 cubic feet per second (cfs) bring all four generators into operation. During periods of water storage, flow releases are only 150 cfs and no electricity is generated. This peaking regime results in water level fluctuations of eight feet in the five-mile stretch of the South Fork below the dam and up to five feet in the main Flathead River downstream.

The schedule of Hungry Horse Dam operation is extremely variable. Releases are sometimes managed on a daily cycle, with peak discharge and power generation in the morning and evening, separated by hours of minimum discharge with no generation. At other times, peak power production continues nonstop for weeks. These periods of maximum discharge draw down the reservoir and consequently are followed by days or weeks of minimum flows when Hungry Horse is allowed to refill.

The water discharged into the South Fork by Hungry Horse Dam is drawn from a depth of 250 feet below the reservoir surface at full pool. This water, largely insulated from the effects of solar heating and radiational cooling, remains between 37-45° F throughout the year. The South Fork's stable temperatures differ from the thermal regime in the North Fork, Middle Fork and main Flathead River, where average daily temperatures range from 33° F in the winter to 65° F in the summer. As an annual average, temperatures on the South Fork are considerably cooler than in the unregulated waters, although the South Fork does experience higher winter temperatures and its surface does not freeze.

Discharges from the dam also differ in chemical composition from waters in free-flowing Flathead streams. Sediments carried by the upper South Fork settle to the bottom of Hungry Horse Reservoir, while associated nutrients and organic compounds are retained in the reservoir by the plant and animal community. This "sink" effect is most noticeable during spring runoff, when the clear waters of the lower South Fork contrast sharply with the turbid flows characterizing other tributaries of the Flathead River.

The substrate of the South Fork has been significantly altered by Hungry Horse Dam. During the dam's 30 years of operation, high flows have flushed sediments and gravel from the stream bottom, while the upstream replacement flow of these materials has been isolated above Hungry Horse Reservoir. Large cobbles and boulders now constitute the bed of the lower South Fork, and this substrate has been compacted or "armored" through the force of high water flows. The favorable water temperatures during winter and the lack of annual sediment scour have allowed dense mats of filamentous algae to become established on permanently wetted portions of the South Fork bottom.

Aquatic insects in the lower South Fork. The aquatic insect community in the lower South Fork is much less diverse than communities in the unregulated sections of the Flathead River system. Only seven species of stoneflies, five species of mayflies, and one species of caddisfly are believed to complete their life cycles in the altered stream environment below Hungry Horse Dam. Populations of these insects are suppressed, comprising a combined 4% of total insect numbers and 23% of insect volume compared to 75% of numbers and volume in the main Flathead River above the South Fork confluence.

Midges are extremely abundant in the regulated South Fork composing 85% of total insect numbers and 48% of insect volume. These percentages are four times the abundance and volume percentages of midges in the Flathead River above the South Fork. Non-insect aquatic invertebrates, including nematodes (roundworms), flatworms, water mites, and oligochaete worms, are considerably more abundant in the regulated South Fork than in the Flathead River.

Perennially cold temperature is the most important factor limiting aquatic insect diversity on the lower South Fork. The nymphs and larvae of most mayflies, stoneflies, and caddisflies require seasonal warming to meet their heat budget and complete maturation; however, the spring and summer temperatures in the South Fork do not exceed 45°. The seven stonefly species which do maintain reproducing population are all winter emergers with very low degree-day requirements. The mayflies in the lower South Fork also have low temperature requirements.

Midges and *Baetis* mayflies are extremely successful in the South Fork by virtue of their ability to develop in cold waters and to inhabit and feed on the thick growth of filamentous algae which covers the South Fork bottom. The non-insect aquatic invertebrates in the South Fork do not have terrestrial adult forms and are able to mature in cold water.

The simplified benthic habitat also plays a role in eliminating species from the South Fork aquatic insect community. The absence of sediments or fine gravels excludes insects adapted to these substrates, while the armored bottom blocks access to the hyporheic zone, a critical area for the early development of many insect species. Insects dependent on habitat near the stream bank also drop out of the community due to the unpredictable flow reductions, which probably left many shoreline insects susceptible to freezing or drying out, or stimulated downstream dispersal from the South Fork through the behavioral phenomenon of catastrophic drift.

Filtration of organic material by Hungry Horse Reservoir has changed the quality of food resources available to aquatic insects. In unregulated river sections, fine organic particles, carried from upstream areas and deposited in backwaters or pools sustain the small instars of most aquatic insect species. In the South Fork, this key food source is absent.

Aquatic insects in the mainstem Flathead River. The Flathead River below its confluence with the South Fork is influenced by both natural riverine cycles and regulated flow releases from Hungry Horse Dam. This river section, termed "partially regulated", receives a substantial inflow of suspended sediments and organic particulate during spring runoff and maintains the mix of substrate types characteristic of free-flowing Flathead waters. The effects of the South Fork are expressed in the drastic flow fluctuations, which can

Sorting insects in Freshwater Research Lab at UMBS quickly raise or lower water levels in the Flathead, and through temperature effects, which result in warmer-than-normal water temperatures during winter and cooler temperatures during summer.

Surprisingly, despite the influence of the South Fork releases, aquatic insect diversity and population density in the partially regulated Flathead are very similar to diversity and density in the unregulated waters of the main Flathead River above the South Fork mouth. The composition of the aquatic insect communities, however, differs significantly between the two sections. Many of these differences can be traced to the influence of South Fork flows.

A 50% reduction in mayfly populations in the partially regulated section is the most striking change in community composition. Mayfly losses are attributable to the drastic flow fluctuations which alternately flood and dewater the key shoreline environment. The large stonefly *P. badia* increases in numbers below the entry of the South Fork. This positive population response reflects the greater availability of coarse particulate organic matter, most of which derives from the dense algae growth in the South Fork. The stonefly nymphs also feed on terrestrial plant materials washed into the partially regulated section when high South Fork releases sweep the shoreline riparian zone.

Two caddis species were significantly more abundant in the partially regulated section. *Arctopsyche grandis,* a large net-spinning caddis, benefits from the large organic particles, primarily broken pieces of filamentous algae, which drift into the mainstem Flathead from the South Fork. *Glossosoma,* an algal scraper, finds substantially increased algal growth in the partially regulated section. This species can firmly affix its case to rock surfaces and is able to withstand the force of maximum South Fork releases.

The reduced annual total of degree-days caused by cold Hungry Horse Dam waters is also a factor in the shift of species in the partially regulated Flathead River. Many caddis species are unable to mature in the cool summer temperature regime and drop out of the insect community below the South Fork mouth. Additional detailed life history studies are needed to determine the precise changes in species composition which can be attributed to the reduced heat budget in the partially regulated waters.

The temperature of South Fork waters also alters emergence timing in the mainstem Flathead River. Caddis, mayflies, and stoneflies which grow most rapidly during the warm season experience slower growth, and emerge a month later, in the partially regulated section than in the unregulated waters. Conversely, winter-developing stoneflies in the partially regulated Flathead are subject to warmer temperature during their growth phase and emerge a month earlier below the mouth of the South Fork.

The Flathead River Continuum

As documented throughout the Flathead River system, the riverine environment varies in a gradual but continuous manner along the course from headwater tributaries to major rivers. Changes in temperature, flow volume, suspended and dissolved solids, and other physical and chemical factors induce complex responses in aquatic plants and insect communities. Research on selected streams provides an overview of the continuum of ecological changes that characterize the Flathead drainage (Table 5.3).

The headwaters (1st order streams) of the Flathead River system fall into two distinct categories. Springbrooks, the most common type, originate from groundwater flowing from the porous limestone bedrock of the upper Flathead River drainage. These streams, with their sources well-insulated from surrounding weather conditions, maintain a constant, relatively warm temperature and an even flow volume. Such stable habitat conditions result in a low diversity of aquatic insect species. Despite high concentrations of dissolved calcium, productivity by aquatic plants is generally low in springbrooks because of severe shading by the riparian vegetation and a lack of other essential nutrients.

Alpine meadow creeks, the other 1st order tributaries of the Flathead River system, emerge at high altitudes close to snow banks. These open-canopied, high-elevation waters have cold average temperatures, but experience seasonal warming due to solar heating in the summer. Aquatic insect diversity is greater than in the springbrook community, reflecting the more diverse temperature regime and habitat conditions in the alpine creeks.

Merger into progressively larger streams mutes the habitat differences between the two types of 1st order headwaters. The 2nd and 3rd order tributaries of the Flathead River are rushing forest streams, with cold waters that reach a summer maximum of only 50°. Primary productivity is low, and leaves and other terrestrial plant litter provide most of the biological energy to the aquatic system. Shredders and collectors of coarse organic particles dominate the aquatic insect community, and diversity is moderate.

TABLE 5.3

Biophysical attributes measured along the Flathead River continuum.

Parameter	Stream Size (order)					
	$1_{(a)}$	$1_{(b)}$	2.3	4	5	$6_{(c)}$
Mean Annual Degree Days	1070	2200	1300-1500	1900	2400	2050-2600
Annual T (°C)	24	0.5	10.5	12.5	17	26-20
P/R ($X_{(n)}$)	—	$.81_{(6)}$	$.99_{(9)}$	$1.30_{(10)}$	$1.93_{(8)}$	$1.45_{(8)}$
NCPP*	—	133	178	768	607	1063
Number of Plecoptera Species	19	13	29	27	40	42

$^{(a)}$ tundra (alpine) stream

$^{(b)}$ lowland springbrook

$^{(c)}$ regulated segment

$^{(n)}$ number of community metabolism analyses

* average net community primary productivity

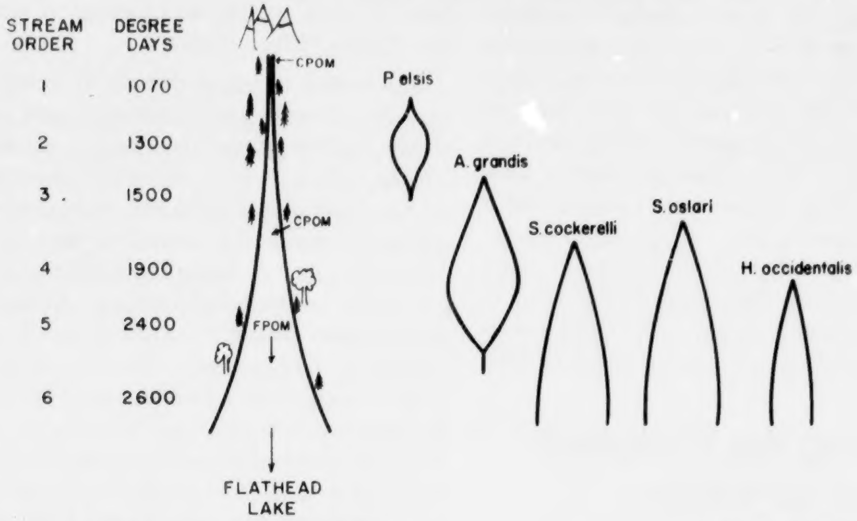
The 4th order streams, typified by Trail Creek and other large tributaries of the North and Middle forks, have more open canopies, slightly warmer water temperatures, and gentler gradients than their lower order tributaries. These conditions stimulate an increase in algal growth in the 4th order waters, although the shortage of nutrients throughout the Flathead drainage keeps primary productivity well below levels found in most other river systems in temperate climates. The increased populations of minute algae are combined with terrestrial plant litter to provide a mix of coarse and fine organic particles. Filter feeding insects, better able to use the fine particles, become more abundant, and diversity in the insect community increases.

The North Fork and Middle Fork, the two free-flowing 5th order streams, and the 6th order main Flathead represent the final stages in the river continuum. Many different substrates, current speeds, and food types, along with large seasonal fluctuations in temperature and flow volume, provide an exceptionally wide array of habitat conditions in both space and time. Algae continue to be an important source of energy for aquatic insects in these warmer, unshaded waters; together, algae and the processed organic compounds from upstream sources supply the fine organic detritus required by developing nymphs and larvae. The combination of food, habitat, and seasonal environmental variations allows scores of aquatic insect species to coexist by partitioning resources and segregating life histories to reduce competition. As a result, the Flathead rivers maintain one of the most diverse aquatic insect communities in North America.

Life history studies of net-spinning caddis have documented a successional pattern along the continuum gradient from small 2nd order streams to the 6th order Flathead River (Fig. 5.9). *Parapsyche elsis,* a larva which requires only 1,200 to 1,400 degree-days to complete its development, is the dominant net-spinning caddis in cold waters of 2nd order streams. This species spins a net with a relatively large mesh and filters coarse organic particles from the current. In 3rd and 4th order tributaries, *P. elsis* is joined and gradually replaced by *Arctopsyche grandis. A. grandis* also has a net designed for capturing large organic particles (with mesh openings up to 0.5 mm), but requires warmer conditions than *P. elsis*. Three net-spinners adapted to utilize fine particulate organic matter and to develop under a relatively high thermal regime become important members of the caddis population in

FIGURE 5.9

Hypothetical Distribution of Hydropsychidae Caddisflies Along Undisturbed River Continuum



5th order waters of the North Fork and Middle Fork. *Symphitopsyche cockerelli*, *Symphitopsyche oslari*, and *Hydropsyche occidentalis* coexist with *A. grandis* over a considerable range; however, as temperatures continue to warm and the concentration of coarse organic particles decreases, *A. grandis* drops out of the community. *S. cockerelli*, *S. oslari*, and *H. occidentalis* are the dominant caddis species in the 6th order Flathead River. Seasonally staggered development cued by temperature reduces competition and allows these three closely related species to coexist.

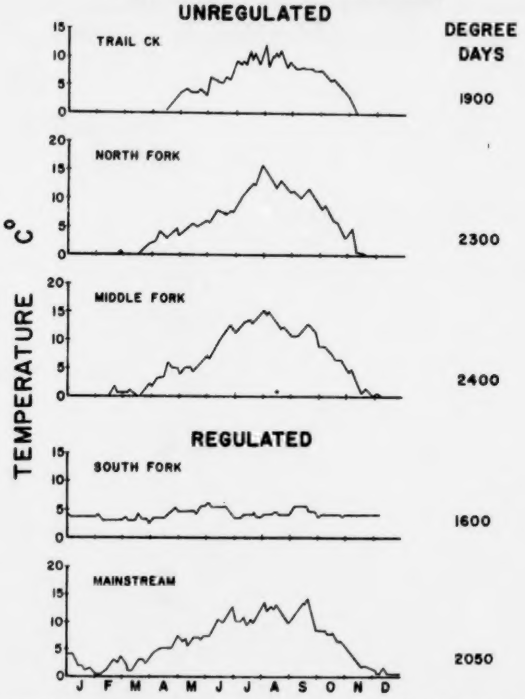
River Reset

Certain habitat conditions in the Flathead River below its confluence with the South Fork resemble lower order streams. Concentrations of coarse particulate matter are elevated due to sloughing of the algal mats which carpet the bottom of the South Fork. High discharges from Hungry Horse Dam add to the coarse organic particle load by recruiting leaf litter into the Flathead River from its banks. The annual temperature regime shows a reduced number of degree-days because of the cold South Fork flows (Fig. 5.10).

In response to these altered conditions, the caddisfly populations shift to species adapted to lower order streams. *Arctopsyche grandis*, which normally reaches maximum abundance in 4th order streams, becomes the dominant caddis with the coarse organic particles and cooler temperatures of the partially regulated section of the 6th order Flathead River. *Symphi-*

FIGURE 5.10

Annual Temperature Regimes Flathead Rivers, Montana



Thermal regima and temperature summations measured in 1979 at selected creek and riverine sites on the Flathead River continuum (taken from Hauer & Stanford 1982).

topsyche cockerelli, Symphitopsyche oslari, and *Hydropsyche occidentalis*, three caddis species which require warmer water temperatures and fine organic particles, are greatly reduced in number below the South Fork mouth. The effect of Hungry Horse releases in establishing the environmental conditions and insect populations of lower order tributaries in the 6th order Flathead River is termed a river reset (Fig. 5.11). A reset in the opposite direction (to large river conditions within small stream environments) occurs at the outlet of mountain lakes. Streams flowing from lakes have warmer than normal temperatures and a relative shortage of large particles. Species composition in these stream outlets is characteristic of large river insect communities. Examples of this shift in aquatic insect populations occur in streams below Kintla Lake and other lakes on the west slope of Glacier National Park.

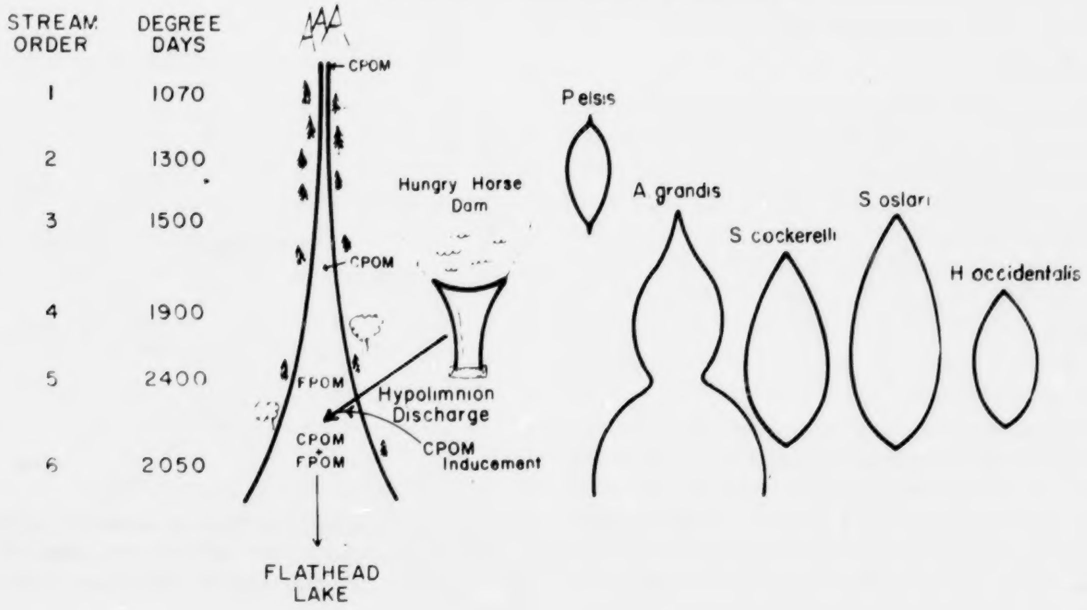
Monitoring the Flathead River Ecosystem

Research conducted through the Flathead River Basin Environmental Impact Study has documented the current status of the Flathead River ecosystem and the factors affecting its biological communities. As land-use activities alter the Flathead watershed, careful monitoring of the river system will be necessary to detect changes from baseline conditions. Researchers have recommended a program to monitor suspended solids, water temperature, and organic carbon concentrations because these characteristics strongly influence water quality and biological communities in the Flathead River system.

Monitoring of suspended solids would indicate the quantity of sediments transported from the land to the stream system. Land uses which increase the total stream sediment load or which generate sediments during base-flow conditions could dramatically alter stream bottom habitat and adversely affect aquatic insect communities. Sediment additions might be most damaging in the small tributary streams which now remain clear even during runoff and thus do not have biological communities adapted to high sediment loads. Monitoring sediments would also have crucial application to conserving water quality in Flathead Lake and maintaining trout populations throughout the Flathead aquatic system, as detailed in the following subchapters on lake ecology and fisheries.

Water temperatures sequence aquatic insect life cycles and determine the species composition within particular stream segments; a monitoring program would provide a way to assess the potential impacts of temperature changes in the insect community.

FIGURE 5.11
Distribution of Hydropsychidae Caddisflies With Hungry Horse Dam



Coal seam and overburden, Cabin Creek Coal Mine Site, North Fork Flathead River Valley, British Columbia

Changes in flow releases from Hungry Horse Dam would alter the downstream thermal regime and further impact insect populations in the partially regulated mainstem Flathead River. Timber harvest and small-scale hydropower development also have the potential to modify water temperatures in the Flathead system, either through the removal of streamside vegetation or through changes in streamflow patterns.

Monitoring of particulate organic carbon concentrations in the river system should give a measure of the productivity of the stream environment for plants and the food availability for aquatic insects. The supply of particulate organic carbon in the sediments represents a critical food for aquatic insects. Laboratory analyses of the organic detritus-clay mixture from the North Fork indicate that organic carbon constitutes 2.5% of the weight of the fine bottom sediments. Nitrogen content, which indicates the presence of proteins, amino acids, and other highly nutritive compounds, is one-twentieth of the organic carbon concentration.

Although of little meaning by themselves, these figures set a baseline for the organic composition of benthic sediments in the Flathead drainage. This baseline chemistry is particularly important in light of the proposed coal mining in the upper North Fork. Coal dust or other sediments released from the mine would drastically alter the composition of the sediments to the detriment of the aquatic insects which use this rich organic material. Current analyses of the North Fork sediments indicate that no coal dust is now being transported downstream in the North Fork.

The association of certain aquatic insect species with specific habitats along the river continuum provides a means to monitor environmental conditions as reflected in biological communities. Researchers investigating the Flathead River system have identified a number of "marker species", each abundant in a particular stream order (Table 5.4). The absence of appropriate marker species in insect samples would indicate that temperature, food, or habitat resources have been significantly altered, and would alert researchers to investigate other ecosystem components. For example, the loss of an insect species dependent on a clean gravel environment might suggest problems for developing trout eggs, which require a similar habitat for successful hatching. Sampling for marker species in 4th, 5th, and 6th order waters can also indicate whether the cumulative impacts of upstream development have been sufficient to disrupt downstream biological communities.

TABLE 5.4

Flathead River System Aquatic Insect Marker Species

Species of benthic insects and respective trophic designation as predictors of stream size in unaltered segments of the Flathead River system.

Stream Order	Marker Species	Functional Group
1a	Yoraperla brevis	Shredder
	Rhyacophila vobara	Collector
1b	Perlomyia utahensis	Collector
	Tipulidae Spp.	Shredder
2	Setvena bradleyi	Engulfer
	Rhyacophila coloradensis	Collector
3	Parapsyche elsis	Collector
	Sweltsa borealis	Engulfer
4	Arctopsyche grandis	Collector
	Megarcys watertoni	Grazer/Engulfer
5	Hydropsyche Spp.	Collector
	Isoperla fulva	Collector
	Rhithrogena hageni	Scraper
6	Hesperoperla pacifica	Engulfer
	Claassenia sabulosa	Engulfer
	Ephemerella inermis	Scraper

River Ecology Summary

The Flathead River system is characterized by clear waters of low nutrient content and low algal productivity. During late spring, snowmelt runoff greatly increases stream volume and causes extensive erosion of natural sediment banks along the forks of the Flathead and their immediate tributaries. Most of these sediments are extremely fine and are carried through the river system to Flathead Lake, rather than being deposited on the stream bottom.

Terrestrial sources, particularly autumn leaf fall, make significant additions of organic carbon to headwater streams. In downstream river sections, photosynthesis by algae represents the most important source of energy for biological communities.

Aquatic insect biomass is low, reflecting the limited amount of organic material throughout the Flathead River system. Insect diversity, however, is exceptionally high as a result of intricate partitioning of food and space resources among different insect species. Genetically programmed responses to water temperature determine species distribution along the river continuum and also sequence the life histories of closely related species to permit coexistence. Fine organic particles amidst the stream bottom sediments provide food for the young instars of nearly all aquatic insects, and the loosely compacted flood plain gravels serve as an important habitat for early development. Insects play a key ecological role by packaging energy in a form that can be used by fish.

Environmental alterations caused by Hungry Horse Dam simplify the aquatic environment by flattening out the annual temperature regime and eliminating characteristics of the stream bottom habitat. As a result, insect diversity is extremely low in the regulated South Fork. In the partially regulated Flathead River below the South Fork mouth, insect diversity is comparable to that found in the unregulated river sections; however, species composition is markedly different in response to temperature and habitat conditions which resemble those of lower order streams.

Suspended sediments, temperature, and organic carbon concentrations have important implications for water quality, stream habitat, and biological productivity. A program to monitor these characteristics will allow researchers to detect changes in the stream environment. The quantity and nutritive quality of the organic particle-clay complex on the stream bottom is another critical ecosystem indicator which should be monitored to indicate food quality for aquatic insects. Sampling for marker species of aquatic insects provides a method to assess biological conditions in each of the six stream orders in the Flathead River system.

THE ECOLOGY OF FLATHEAD LAKE

The aquatic environment of Flathead Lake is strongly influenced by inflowing waters from the Flathead and Swan rivers. Natural events and human activities throughout the upper Flathead drainage add sediments, nutrients, ions, and organic matter to the rivers, and most of these constituents are ultimately discharged into the lake. This riverine inflow plays a profound role in shaping the water quality and biological communities of Flathead Lake.

Research conducted through the Flathead River Basin Environmental Impact Study documented the physical, chemical, and biological processes in Flathead Lake and detailed how discharges from the rivers influence lake ecology. The research also thoroughly catalogued existing conditions in the lake, thus establishing a baseline against which future changes can be judged. The information gained through the five-year study forms the basis for a program to monitor the critical components of the Flathead Lake ecosystem and for action to conserve the lake's natural values.

Physical and Chemical Conditions

Flathead Lake collects water from a 4.5 million acre drainage, encompassing the upper Flathead River system, the Swan River, and small stream watersheds emptying directly into the lake. The lake discharges into the lower Flathead River at Polson. With a maximum length of 27 miles, a maximum width of 15 miles, and a surface area of 126,000 acres, Flathead Lake has the largest surface area of any natural freshwater lake in the western United States (Table 5.5).

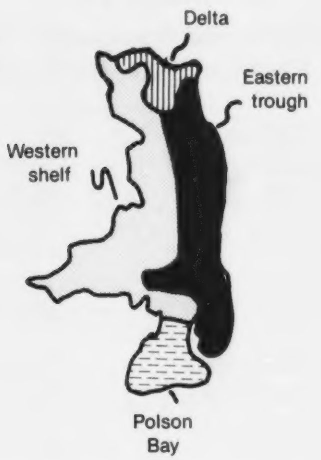
TABLE 5.5
Morphometric and Hydrologic Features of Flathead Lake, Montana.

Elevation (full pond)	882.4 m
Elevation (low pond)	879.0 m
Maximum length	43.9 km
Maximum width	24.9 km
Mean width	10.5 km
Maximum depth	113.0 m
Mean depth	50.2 m
Area	
Total (full pond)	510.2 km^2
Total (medium-full pond)	486.9 km^2
Islands	14.3 km^2
Water	495.9 km^2
Drainage basin	18,378.6 km^2
Volume	23.2 km^3
Hydraulic retention time	2.141 yr
Hydraulic loading	23.5 m/yr
Shoreline	
Total	301.9 km
Mainland	259.7 km
Islands	42.2 km
Mean Annual Discharge	10.9 km^3

Although distinguished by its surface area, Flathead Lake is of only moderate depth, reaching a maximum of 370 feet and an average of 165 feet. Both Tally Lake and Lake McDonald in the Flathead Basin attain greater maximum depths while Lake Tahoe, with a surface area nearly equal to Flathead Lake, reaches depths exceeding 2,000 feet. Flathead Lake can be divided into four distinct regions based on depth characteristics (Fig. 5.12). The shallow delta is located at the mouth of the Flathead River at the extreme north end of the lake. The deposition of sand and other materials during spring runoff has built up the lake bed here, and depths are generally less than 20 feet. A relatively level-bottomed shelf comprises the west half of Flathead Lake. This region, which begins just beyond the steep shoreline dropoff, ranges in depth from 80 to 150 feet. A deep trough reaching depths greater than 300 feet underlies the entire eastern half of the lake. Polson Bay composes the southern end of Flathead Lake. The bay, isolated from the main body of the lake by an island-dotted strait called the Narrows, is generally less than 25 feet deep and constitutes the most extensive shallow area of the lake.

FIGURE 5.12

Flathead Lake Depth Regions



Hydrology

The Flathead River annually discharges 7.6 million acre-feet of water into Flathead Lake, while the Swan River adds another 880,000 acre-feet. The considerable influence that these rivers exert on Flathead Lake can best be understood in light of the relative volumes of the lake and river waters. During an average year, Flathead Lake receives an inflow of 8.8 million acre-feet of water, most of which comes from the major river tributaries. The lake volume is 18.8 million acre-feet, or about 2.1 times greater than the annual inflow. In other words, almost half of the lake volume is replaced by river water each year.

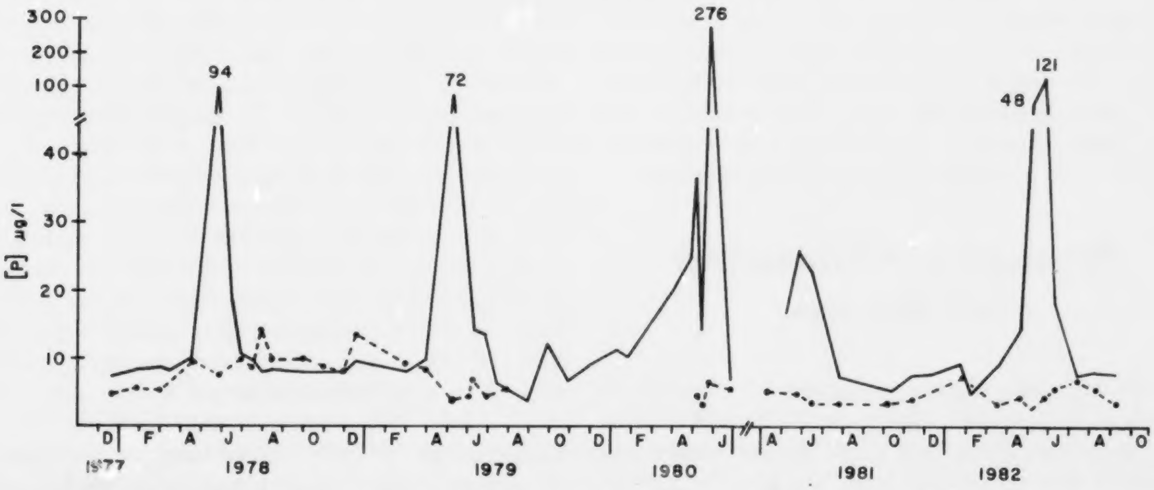
This replacement rate is rapid for a large lake. In contrast, water in Lake Tahoe has a residence time estimated at 700 years, reflecting its extreme depth (and hence large volume) and the lack of a major river inflow and outflow.

Sediment Plume

Spring runoff from the Flathead River system provides a dramatic seasonal influence which changes the clear blue waters of Flathead Lake into an opaque, coffee-and-cream mixture. The effectors of this color transformation are fine clay particles washed primarily from the banks of the North and Middle forks and their larger tributaries. An annual average of about 150,000 tons of suspended sediment is discharged into Flathead Lake by the Flathead River during the month-long peak runoff. This amount can vary considerably between years, however, as high runoff flows carry much more sediment than flows during years of low runoff. Most of the sediment derives from natural erosion of the unstable river banks, but land-use activities in the upper Flathead drainage have added to the sediment load.

Although the timing of the runoff event varies with weather and snowpack, a general pattern of discharge is common to most years. Beginning in early spring,

FIGURE 5.13



Concentrations of total phosphorous (solid line) and dissolved phosphorous (broken line) in the Flathead River at the inflow to Flathead Lake rain and low-elevation snowmelt combine to send pulses of high water and sediments through the Flathead River. Intermittent cold spells, however, halt the snow melt and often allow the water to clear before much sediment enters the lake. With warmer May temperatures and more frequent rains, Flathead River flows increase steadily and sediment discharge into the lake attains its maximum level.

The initial contact of the surging runoff with the stable water mass of Flathead Lake slows the river waters and allows sand and heavier particles to settle to the lake bottom. These settled sediments are responsible for the delta islands and marshes located near the river mouth. Silt and clay particles less than about 10 microns in diameter remain suspended as the river current pushes the water southward into the lake. These particles initially form a layer extending from the surface to a depth of 30 feet.

Temperature differences between the river and lake are an important factor in carrying the fine sediments beyond the delta region. During their downstream course, river waters warm because of contact with the ambient air temperatures, while the temperature of the lake water column rises very slowly from its cool-season minimum. Because warmer water is less dense (lighter in weight), the flow entering Flathead Lake strongly resists mixing with the colder, denser lake waters. The result is a narrow layer of river water sliding across the surface of the lake. This highly visible, sediment-laden flow is termed the spring turbidity plume (Fig. 5.14).

Upon entering Flathead Lake, the river flow is deflected to the west toward Somers. This current, highly visible during the period of the sediment plume, is an expression of the Coriolis effect, the counterclockwise motion that the earth's rotation imparts to moving objects in the Northern Hemisphere. After reaching the west shore, the river waters continue their counterclockwise course and begin to head south. During this southerly progression, the plume generally hugs the western shoreline, taking about three weeks to travel from Caroline Point to the Narrows above Polson Bay. The lake can present a striking aerial view during this time, with the west side appearing murky and tan and the east side remaining clear and blue. Westerly storms and resulting wave action, however, sometimes blur the sharp dividing line by spreading sediment-laden waters across the lake to the east.

The plume divides upon reaching the Narrows. One branch continues southward and spreads into Polson Bay, while the other branch heads east toward Finley Point. This latter branch of the turbidity plume completes its counterclockwise journey by heading north along the east shore. Woods Bay and mid-lake regions are among the last waters to receive the spring runoff sediments.

Plume development usually encompasses a month from the entry of the main runoff flow in late April and early May until complete coverage of Flathead Lake in late May or early June. The surface waters clear within another two to three weeks, and the fine clay and silt sediments settle through the entire water column in six to eight weeks.

Temperature Stratification

Seasonally changing temperatures control the vertical circulation of Flathead Lake waters. The temperature regime has a profound influence on nutrient availability, productivity, and the populations of aquatic plants and animals.

As air temperatures warm in late spring, waters near the lake surface heat most rapidly. This top layer, or epilimnion, is less dense than the underlying water column, and resists mixing with it. Circulation caused by wave action promotes relatively uniform conditions within the epilimnion, which extends to a depth of 25 to 50 feet. Epilimnion temperatures range from 50°F during spring and autumn to nearly 70° at the summer maximum.

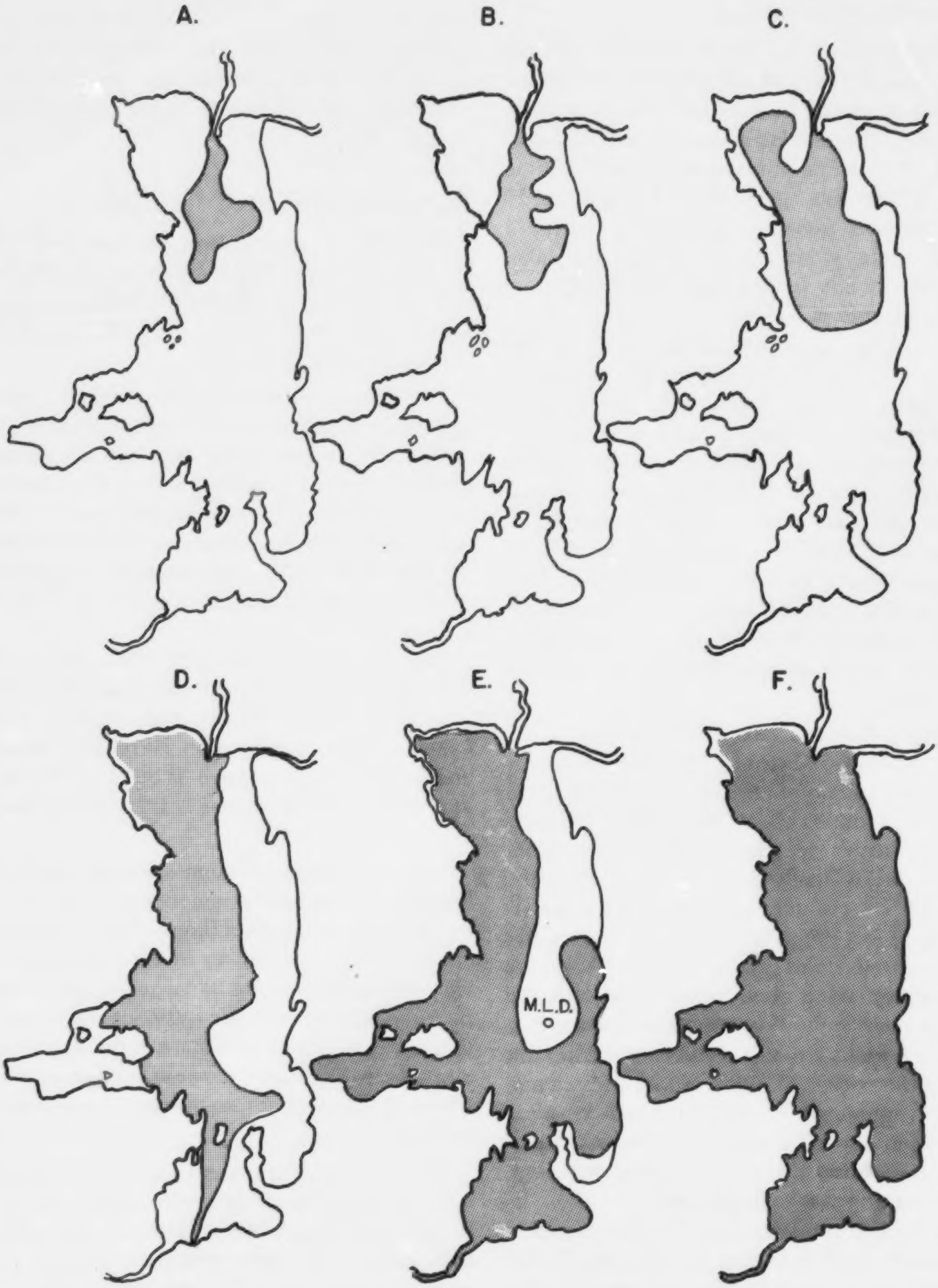
Below the epilimnion lies the thermocline, a 50-foot-thick band with water temperatures that rapidly decline with depth. During mid-summer in Flathead Lake, water temperatures in the middle reaches of the thermocline drop as much as one degree per vertical foot. Temperatures at the bottom of the thermocline average about 43°.

The hypolimnion encompasses the deepest zone of Flathead Lake, where temperatures remain between 38° and 42° throughout the period of summer stratification. Summer warming of the hypolimnion occurs very slowly because of its large volume of water and because little direct solar radiation reaches below the thermocline. The cold waters of the hypolimnion are more dense than the warmer upper layers, a condition which strongly reinforces the stability of summer stratification.

Thermal stratification in Flathead Lake usually dissipates during mid-autumn, when cold weather rapidly drops water temperatures. Surface waters in contact with the cold air mass cool most quickly, but strong winds blowing across the lake induce a vertical circu-

FIGURE 5.14

Movement of Typical Sediment Plume In Flathead Lake



lation from the surface to the bottom of the lake. This circulation, or "turnover", lasts through the winter and plays an important role in nutrient cycling. Organic compounds and nutrients which have settled below the zone of most biological activity are carried upward and become available again for use by plants and microorganisms. With the onset of winter, Flathead Lake temperatures drop below 40°, and by January the water column has equilibrated at about 34° to 38°.

The entire lake surface freezes about one year out of ten, with the most recent freeze occurring from January to March, 1979. Because water reaches maximum density at 39°, the frozen or near-freezing surface waters are less dense than the underlying water column. The result is inverse stratification, with stable layers of colder waters resting above the warmer hypolimnion. Inverse stratification only occurs under ice cover, when the lake is insulated from the effects of wind-induced circulation. Consequently, this phenomenon is of greatest importance in the protected bays, most of which freeze over annually. When the ice breaks up in the spring, the surface waters warm to equilibrium with the hypolimnion, allowing spring turnover. This vertical circulation of lake waters continues until summer stratification again sets in (Fig. 5.15).

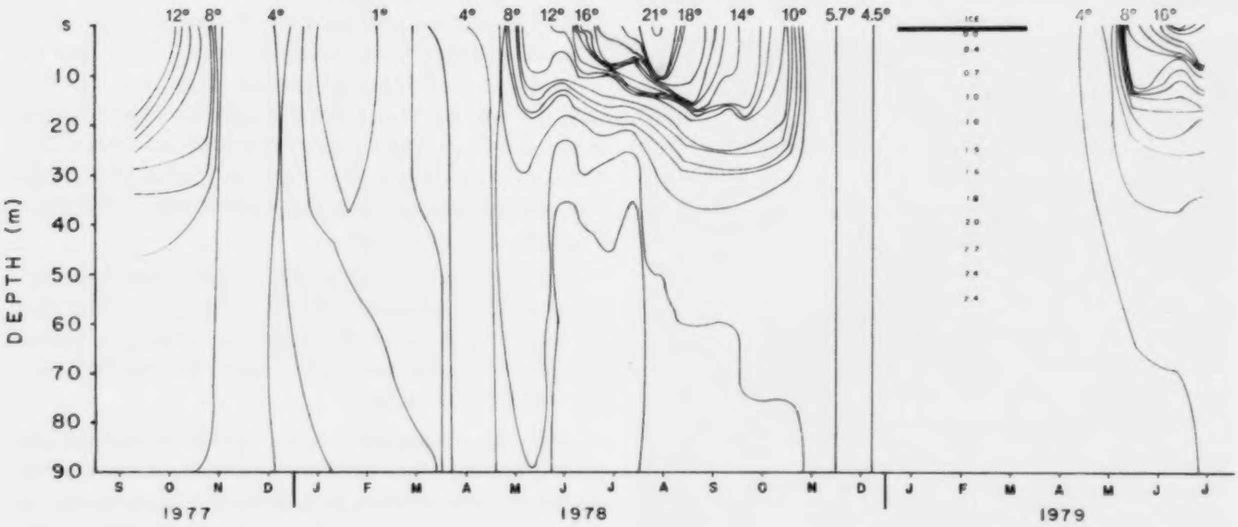
Water Chemistry

Because of considerable river inflow, the chemical characteristics of Flathead Lake generally mirror river conditions. Calcium is the dominant positively charged ion, followed by magnesium. These compounds are both important for the growth of aquatic plants and are present in adequate concentrations. Bicarbonate is the dominant negative ion, giving the lake a slightly alkaline water chemistry and a moderate buffering capacity to neutralize acids.

Phosphorus concentrations are low in Flathead Lake, exhibiting a five-year average of 5.4 micrograms per liter. Phosphorus is a crucial plant nutrient, and the low phosphorus concentrations limit the growth of algae in Flathead Lake. The entry of the sediment plume temporarily increases phosphorus concentrations because of the phosphorus carried by the sediment particles; settling of the sediments restores phosphorus concentrations to pre-plume levels (Fig. 5.13). With the exception of sediment phosphorus, almost all of the phosphorus measured in Flathead Lake is incorporated in plant or animal tissue, thus indicating the high biological demand for this nutrient.

FIGURE 5.15

Temperature isotherms at Mid-Lake Deep station, Flathead Lake, Montana, from fall 1977 through summer 1979.



Nitrogen occurs at about 17 times the concentration of phosphorus in Flathead Lake. Although nitrogen is also an important plant nutrient, a biological surplus of nitrogen exists in the lake; this surplus is attributable to the shortage of phosphorus which limits the ability of algae to grow and thus limits the amount of nitrogen that can be taken up by algae. If phosphorus is added to Flathead Lake, the pool of available nitrogen will readily contribute to increased plant productivity.

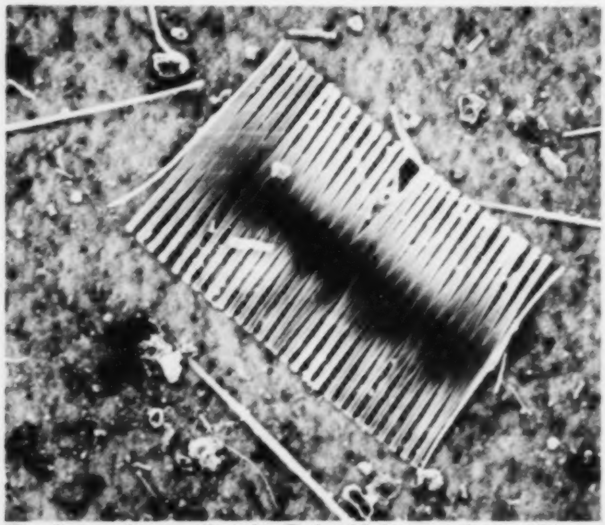
Dissolved oxygen concentrations are uniformly high throughout the Flathead Lake water column. No chemical constituents are present in concentrations high enough to be considered harmful to aquatic life.

Biological Components

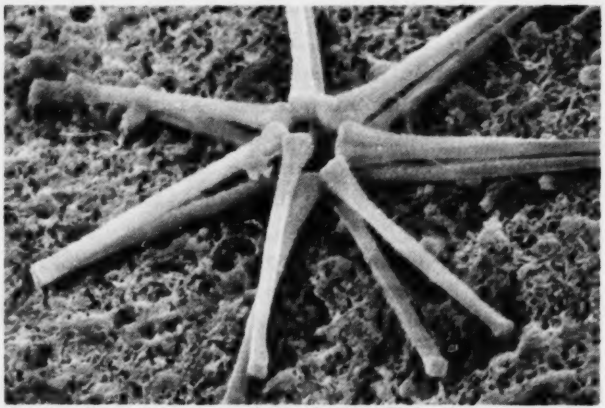
Phytoplankton

The plant community in Flathead Lake is dominated by phytoplankton, a collection of more than 500 species and varieties of microscopic plants that float freely in the lighted zones of the lake. Major categories of phytoplankton include green algae, blue-green algae, diatoms, and dinoflagellates, with representative samples ranging from single-celled organisms to thread-like filamentous forms to complex colonies of mutually interdependent cells. The largest phytoplankton species are about one-half millimeter in diameter; others are hundreds of times smaller.

The small size of the phytoplankton is advantageous for two reasons. First, these single-celled plants resist sinking and are able to remain in the upper, lighted layers of the water column. Second, small size gives the phytoplankton a large surface-to-volume ratio which in turn promotes the efficient uptake of dissolved gases and nutrients from the water.



Fragillaria, a diatom collected in Flathead Lake, magnification 400x



Asterionella, a very common diatom found in Flathead Lake, magnification 1000x

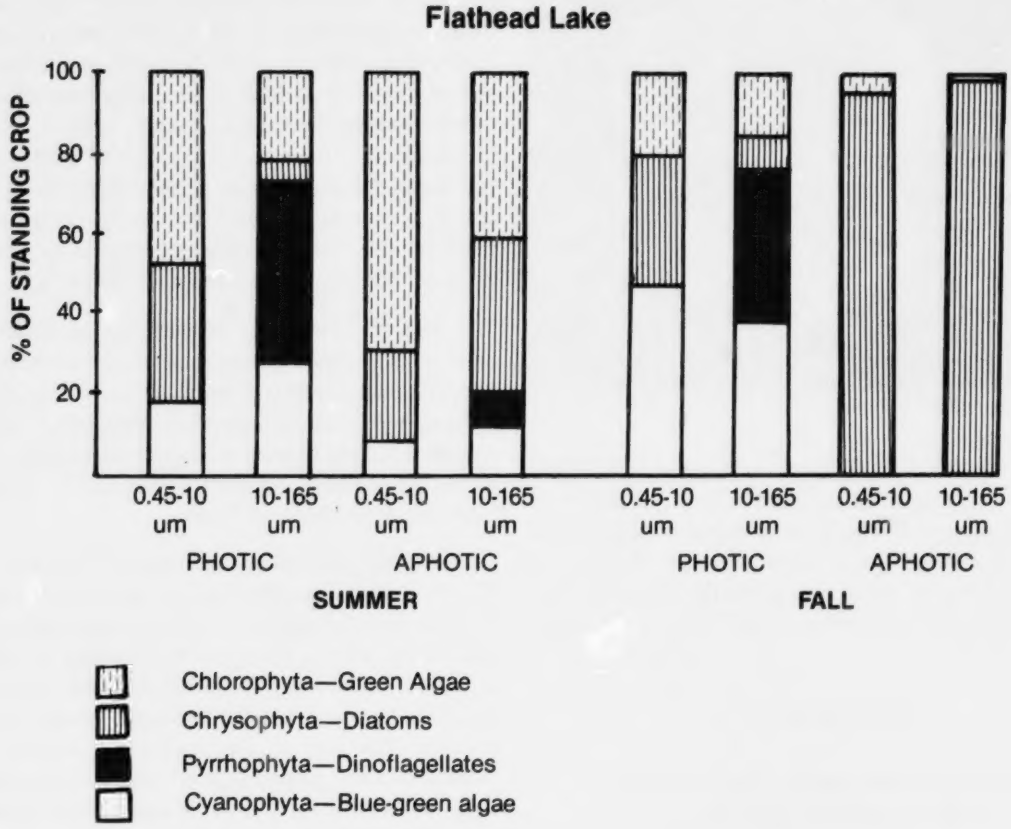
Plankton occur in enormous numbers in Flathead Lake. Summer and fall samples taken at a depth of 33 feet in a typical mid-lake region of Flathead Lake contain about 15,000-20,000 algal cells per ounce of water. (This population density, however, occupies less than one-millionth of the water volume.) The total weight of living plankton (the standing crop biomass) averages about 17 million pounds; the photosynthetic contribution of the Flathead Lake phytoplankton community, based on the weight of carbon from carbon dioxide gas incorporated in organic compounds, is estimated to exceed 140 million pounds annually.

Despite the impressive-sounding numbers, the Flathead Lake phytoplankton community is of relatively low density and volume. A comparative study between Flathead Lake and nutrient-rich Lake Texoma on the Texas-Oklahoma border demonstrated that Lake Texoma averaged about 8 times greater numbers of algae and 35 times greater plankton volume. Comparisons of published data from other lakes worldwide also place Flathead Lake at the lower end of the scale in plankton populations.

The phytoplankton population in Flathead Lake exhibits striking seasonal variation (Fig. 5.16). Changes in temperature, water chemistry, circulation patterns, and light availability all contribute to shifts in the number and kinds of algae.

Most algae species exhibit minimum populations during winter, when cold water temperatures and reduced sunlight inhibit photosynthesis. Small green algae dominate the phytoplankton community at this time, but productivity is low. The increased sunlight in

FIGURE 5.16

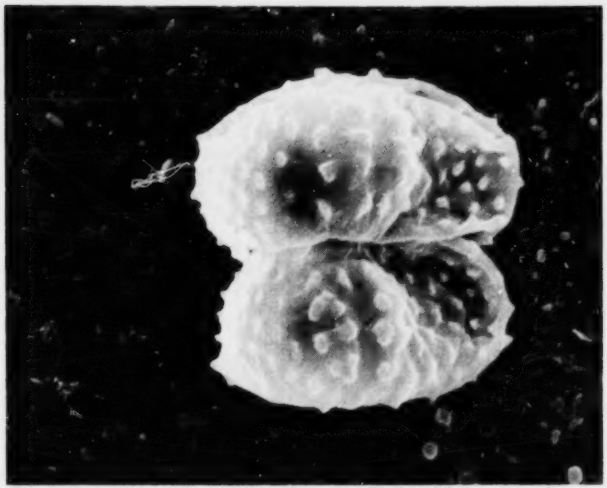


Community composition of phytoplankton in Flathead Lake

spring stimulates photosynthetic activity by the silicon-walled, geometric-shaped diatoms which experience a rapid population increase, or "bloom", during April and May. Species composition shifts markedly during summer. Diatoms decline as the water warms, and green algae (including many species less than 10 microns in diameter) become dominant during early summer. Dinoflagellates, one-celled algae with long spines and whiplike tails, are the most common of the larger phytoplankton. Blue-green algae increase through the warm season, reaching maximum abundance in water temperatures over 60°. During autumn, diatoms achieve another population peak, stimulated by the cooler temperatures and the increased availability of nutrients during the lake turnover. The onset of winter leads to a reduction in the populations of blue-green algae and an increase in the importance of green algae in the phytoplankton community.

The blue-green algae dominant in Flathead Lake during summer are not kinds associated with polluted waters; however, researchers have collected some individuals of the large, filamentous *Anabaena*, a blue-green algae which thrives in polluted waters and which contributes to water quality degradation. The presence of *Anabaena* in Flathead Lake indicates the potential for rapidly deteriorating water quality if changes in aquatic conditions allow a significant population increase by this blue-green algae. The trigger for *Anabaena* blooms in other lakes has typically been an increase in the supply of phosphorus available for plant growth.

Comparison of plankton productivity by size class revealed that ultraplankton (algal species smaller than 10 microns) have a much higher photosynthetic rate than do the larger kinds of algae. Ultraplankton constituted 33-37% of phytoplankton biomass but were re-

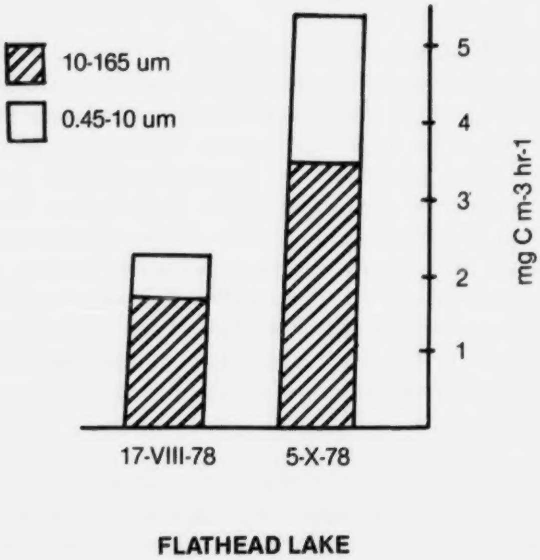


Cosmarium spp., a green algae collected in Flathead Lake, magnification 3000x

sponsible for 65-75% of total primary productivity (Fig. 5.17). This disproportionately high productivity attests to the greater relative efficiency of small algae in obtaining scarce nutrients. Earlier studies of Flathead Lake have failed to sample the ultraplankton community, so its importance has been long overlooked.

FIGURE 5.17

Primary Productivity Partitioned Among Size Fractions.



Bacteria

Despite their minute size and tremendous numbers, algae are neither the smallest nor the most abundant living components of the aquatic ecosystem. These distinctions belong to the bacteria, primitive, single-celled organisms which collectively have the ability to extract energy from almost every organic compound in existence. Three major groups of bacteria are the rod-shaped bacteria, the spherical bacteria, and the spiral bacteria. Bacteria generally range in length from 1 to 10 microns, although chains or other structures of adhering cells achieve a larger size.

Although commonly considered as agents of disease, only a small percentage of the diverse array of bacteria represent a hazard to human health. Such pathogenic bacteria are often associated with waters polluted by septic wastes, but are generally absent or in very low (safe) concentrations in clean water systems, such as Flathead Lake.

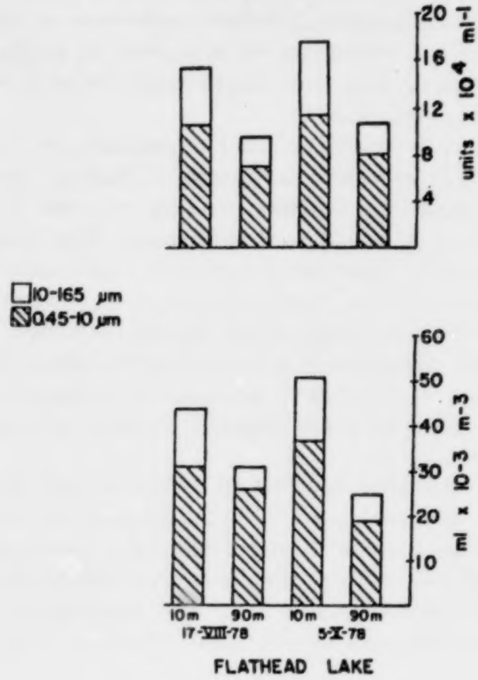
Bacterial populations and growth rates depend on the amount of organic material in the water which, in turn, is directly related to primary productivity by algae. Dead algae, along with dissolved carbon compounds released into solution by living algae, are the major energy sources for bacterial growth and reproduction. Bacteria in Flathead Lake display greatest densities in the upper lighted zones of the water column where photosynthesis by algae is occurring. Bacteria also exist on the lake bottom, where they decompose organic particles which have settled out of the water column.

Even in the clean waters of Flathead Lake, bacterial numbers are almost unfathomably high (Fig. 5.18). Samples indicate bacterial densities up to six million cells per ounce of water. Due to the extremely small size of individual cells, however, bacteria comprise less than one 20-millionth of the total volume of the lake samples, or approximately 95% less volume than is occupied by phytoplankton.

Bacteria in Flathead Lake exist both in a free-floating condition and attached to solid substrates. Most of the attached bacteria are associated with suspended particles of decaying plant or animal tissue, but some bacteria also attach to living algae and presumably obtain nutrients and energy from compounds released by these plant cells. Spherical bacteria and rod-shaped bacteria, including some with long filamentous extensions, are the types of bacteria most commonly found to attach to organic substrates.

FIGURE 5.18

Bacterial Abundance and Standing Crops in Size Fractions.



Considerably less energy is processed by bacteria than by phytoplankton in Flathead Lake. Experimental measurements showed that bacteria assimilate only 1-12% as much organic carbon as algae produce through photosynthesis. Thus, the contribution of bacteria to the dynamics of energy transfer is relatively minor.

Bacteria, however, do play a key role in nutrient cycling and maintaining algal productivity. As algae die and begin to settle to the lake bottom, bacteria colonize and decompose the dead algal cells. Nitrogen, phosphorus, and other nutrients are released into the water through this decomposition and become available for uptake by living algae. Without bacterial activity, the settling algae particles would carry a greater amount of nutrients out of the lighted zone and photosynthetic activity would necessarily be reduced.

Zooplankton

The zooplankton community of Flathead Lake comprises a diverse collection of minute, free-floating animals. Although difficult to see with the naked eye, the zooplankton form a bizarre array of see-through perpetual-motion machines when viewed under a microscope.

Zooplankton depend on phytoplankton for most of their food requirements. Some of the energy transfer is direct, through zooplankters eating living algae, while a significant portion of the energy flow involves zooplankters feeding on organic detritus from decaying phytoplankton. Zooplankters also eat bacteria and other zooplanktonic animals, thus acquiring photosynthetically generated energy in an already processed form. Because of their dependence on phytoplanktonic productivity, zooplankton populations are influenced by a wide range of environmental factors, including temperature, light, sediments, and water currents, as well as competition and predation.

Rotifers, cladocerans, and copepods are the three major groups of zooplankton in Flathead Lake and in most other freshwater lakes. The rotifers resemble

TABLE 5.6

Length (mm) and biomass (micrograms, dry weight) of the principal crustacean zooplankton species in Flathead Lake.

Species	Length range adult female (mm)	Mean length adult female (mm)	Mean biomass adult female (micrograms dry wt.)
Cladocera			
Daphnia thorata	1.37-2.16	1.73	26.2
Daphnia longiremis	1.01-1.53	1.23	10.4
Bosmina longirostris	.34- .60	.46	2.1
Leptodora kindtii	2.8 -5.5	4.1	80.0
Copepoda			
Epischura nevadensis	1.74-2.26	2.01	37.0
Diaptomus ashlandi	.99-1.17	1.09	7.0
Cyclops bicuspidatus thomasi	.94-1.07	1.00	5.5

long-stemmed wine glasses, with their mouth occupying the opening at the top and the internal organs filling the bowl. Rotifers are the smallest of the major zooplankton, with most species less than one-tenth of a millimeter in length.

Planktonic rotifers in Flathead Lake occur in close association with the spring turbidity plume. *Keratella cochlearis* and *Kellicottia longispina*, the dominant species, generally tracked the settling particles to depths of more than 60 feet before dispersing upward through the water column in late summer. The fine particles of organic material attached to clay particles apparently provide a highly desirable food source for these rotifer species, which attained maximum densities of about 100 individuals per liter of lake water.

Copepods and cladocerans are the other major components of the Flathead Lake zooplankton (Table 5.6). These groups are both subdivisions of the crustaceans, a diverse class of hard-shelled animals that also includes shrimp, lobsters, and crabs, as well as the terrestrial centipedes, millipedes, and sowbugs.

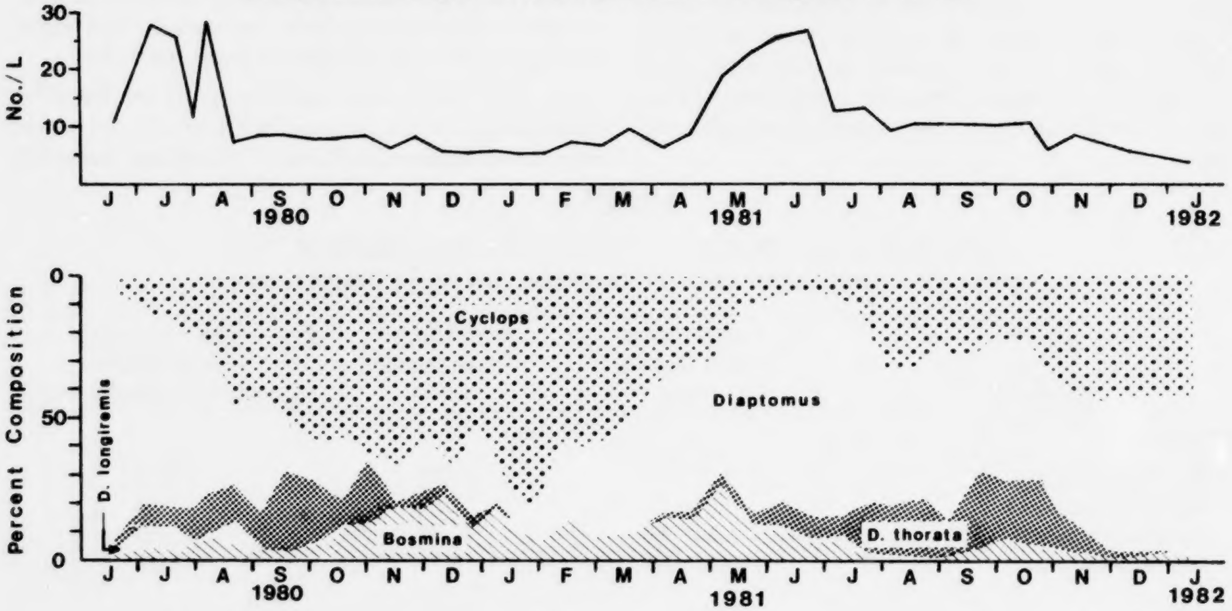
Two species of copepods, *Diaptomus ashlandi* and *Cyclops bicuspidata*, comprised 81% of the numbers of zooplankton (not including rotifers) during extensive sampling conducted from 1980 to 1982. These copepods swim erratically through the water, feeding on algae, detrital particles and, in the case of *Cyclops*, other zooplankters. Both species attain a length of about one millimeter. *Epischura nevadensis*, a predatory copepod averaging two millimeters in length, is much less common, constituting only 0.2% of the zooplankton population.

Cladoceran populations in Flathead Lake are dominated by *Bosmina* and two species of *Daphnia*, the so-called water flea. *Daphnia*, ranging from one to two millimeters in length, are herbivorous filter feeders which rapidly move their five pairs of legs to generate a current of food particles and oxygenated water. The smaller *Bosmina* is also a filter-feeding herbivore. The relatively rare cladoceran *Leptodora*, the largest of the important zooplankters, averages 4 millimeters in length and is an active predator on many species of zooplankton.

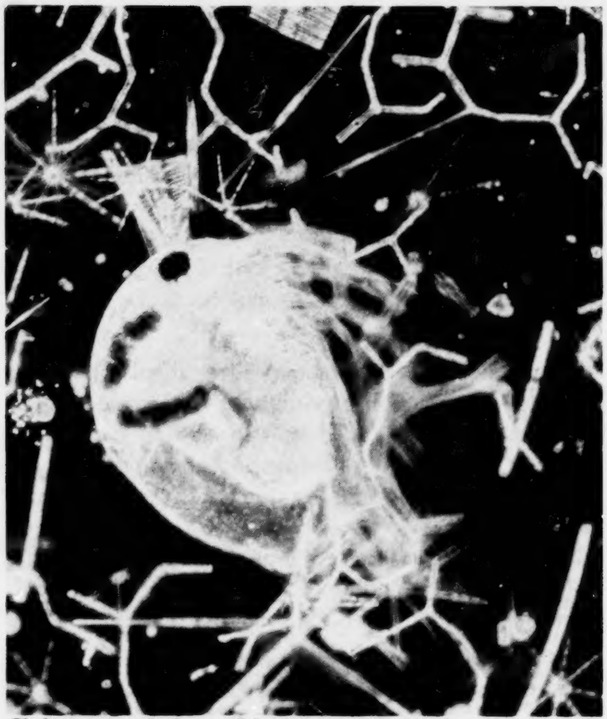
The combined densities of copepods and cladocerans reached a peak of 30 individuals per liter of water during summer, and displayed a minimum of less than 10 per liter during fall through winter. A pronounced seasonal cycle of species composition was evident in the zooplankton community (Fig. 5.19), al-

FIGURE 5.19

Zooplankton Species Composition Throughout the Year



Seasonal fluctuations in total density (No./L; upper figure) and species composition (percent of density; lower figure) of the principal crustacean zooplankton exclusive of copepod nauplii in the surface waters (0-30m) at Station 2:4 of Flathead Lake during the period June 1980 to January 1982.



Cladoceran zooplankton and diatoms in net plankton from midlake, April 1983, photo courtesy Jack A. Stanford

though either *Cyclops* or *Diaptomus* always remained the most abundant species. *Daphnia* overwinter in a resting egg stage and were thus absent from collections taken during mid-January through March.

Zooplankton populations were generally uniform among different areas of the lake. Depth profiles revealed that cladocerans were most common in the upper 50 feet of the water column, while copepods were more evenly distributed from the upper reaches to depths of 80 feet.

The zooplankton in Flathead Lake play a similar ecological role to the aquatic insects in the Flathead River system by acting as the intermediaries through which biological energy made available by plants is packaged for use by fish. The summer population peak of zooplankters can be related to the surge of food energy made available by increased algal photosynthetic activity, while winter population lows reflect the reduced algal productivity at that time.

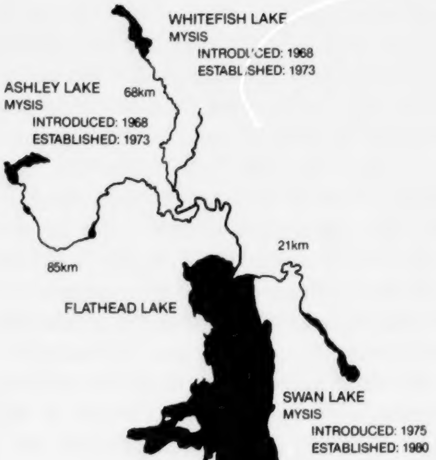
Fish exert a strong influence on the zooplankton community in Flathead Lake by selectively feeding on the larger zooplankters. This pattern of predation, extensively documented for the kokanee salmon, reduces the populations of *Leptodora, Epischura,* and *Daphnia,* and thus contributes to the numerical dominance of the smaller species.

***Mysis* shrimp in Flathead Lake.** Opossum shrimp *(Mysis relicta)* were first collected in Flathead Lake during the fall of 1981. Based on experiences in other lakes in the Pacific Northwest, this discovery may signal some significant future problems for both zooplankton and fish populations in Flathead Lake.

Although not native to the Flathead drainage, *Mysis relicta* naturally occurs in many deep, cold lakes in the northern United States and Canada. During the past two decades, this freshwater shrimp has been widely introduced to enhance food supplies for game fish, particularly kokanee salmon. Whitefish, Swan, and Ashley Lakes now have established populations of *Mysis,* and its appearance in Flathead Lake is the consequence of the inevitable downstream dispersal of the shrimp from one or more of these nearby sources (Fig. 5.20).

FIGURE 5.20

***Mysis* Introductions in the Flathead River Basin**



Map of the upper Flathead River drainage detailing lakes having established *Mysis* populations and distances (river kilometers) to Flathead Lake.

The impetus for introductions of *Mysis* into lakes in the western United States was the success of a 1950 introduction into Kootenay Lake in British Columbia. Kokanee in the lake fed extensively on the one-inch-long shrimp, and maximum weights increased from half a pound to six pounds.

Unfortunately, the success of the shrimp introduction in Kootenay Lake has not been duplicated elsewhere; in fact, kokanee populations have declined significantly in numerous lakes where *Mysis* has become established, including Pend Oreille and Priest lakes in Idaho, Lake Tahoe on the California-Nevada border, and in Whitefish Lake.

These population declines have been traced to the behavior of the shrimp. *Mysis* are a selective predator on *Daphnia,* and can significantly reduce the numbers of this important prey species for kokanee and other fish. Moreover, *Mysis* spend the daylight hours at depths of 300 feet or more, and migrate to surface regions to feed only during darkness. The shrimp are thus unavailable to kokanee, which feed by sight in the upper 100 feet of the water column during the day. Unusual lake currents and lake bed configuration in Kootenay Lake apparently prevented the *Mysis* from escaping to deep-water refuge and thus allowed kokanee to feed on the shrimp and achieve the remarkable size gains.

If the patterns typical of most other lakes in the region hold true, *Mysis* shrimp may become established in Flathead Lake during the next five to ten years. The effect on the fishery, however, is difficult to predict. *Mysis* will certainly feed on zooplankton species now used by kokanee, whitefish, and other fish, but it is unclear whether the shrimp will reduce zooplankton enough to affect game fish growth rates or populations. In a worst case scenario, *Mysis* might drastically deplete critical zooplankters, and thus cause sharp reductions in populations of kokanee, whitefish, and dependent fish-eating species, such as bull trout and lake trout. On the other hand, *Mysis* might become an important available food source for kokanee in shallow areas, such as the Narrows at the mouth of Polson Bay, and thus enhance kokanee populations. Bull trout and lake trout, inhabitants of deeper water, are also known to eat *Mysis,* but no increase in growth rate in the presence of *Mysis* has been demonstrated for these large predators. Research on the food habits of *Mysis* and kokanee salmon, along with careful monitoring of the populations of *Mysis* and other zooplankters will be critical to determining the effects of this introduced shrimp on the biological communities of Flathead Lake.

Trophic Status

Scientists have developed a system to classify lakes having similar physical and biological characteristics (Table 5.7). At one end of the scale are oligotrophic lakes, with low plant productivity and low nutrient content. These lakes are generally deep with clear, cold waters and high concentrations of dissolved oxygen. Oligotrophic lakes characteristically support a coldwater fishery, dominated by species in the trout family.

Eutrophic lakes, on the other hand, display high nutrient levels and high productivity. The water is often clouded by algae, and dissolved oxygen concentrations are low. Fish populations in eutrophic lakes are dominated by rough fish, often including carp and suckers, and warm-water game fish species, such as bass and sunfish. In conditions of extreme eutrophy, waters are grossly polluted by decomposing organic wastes and are unsuitable for fish or for human use.

Mesotrophic lakes display characteristics intermediate between oligotrophy and eutrophy. Classification of trophic status is subjective, particularly for mesotrophy and the slightly less productive category of oligo-mesotrophy.

Eutrophication. Lakes can change from oligotrophic to eutrophic by either natural or cultural (man-caused) pathways. Natural eutrophication, a process which often takes many thousands of years, is initiated by the riverine transport of sediments eroded from the drainage basin into the lake. As the lake fills, it becomes progressively shallower, warmer, and more productive for plant growth. The continued inflow of sediments gradually changes the lake to pond and then marsh, with growing-season water temperatures, plant productivity, and organic content all increasing as the lake fills. Eventually, the combination of inorganic sediments and organic materials may completely fill in the lake, and the eutrohication process is completed.

Cultural eutrophication, which indicates increasing aquatic productivity due to human influences, is caused by the continuous addition of nutrients to a lake. Eutrophication often follows a predictable cycle which results in the deterioration of water quality and the degradation of the aquatic ecosystem. Cultural eutrophication typically begins when nutrients derived from sewage, detergents, fertilizers, or industrial discharges enter the water and stimulate the growth of algae and other aquatic plants. The increase in plant

TABLE 5.7

Annual primary productivity values observed in various lakes of the world in comparison to Flathead Lake (modified after Kimmel and Lind, 1972; Wetzel, 1975; Stuart and Stanford, 1978; Rast and Lee, 1978; Vollenweider and Kerekes, 1980 .

Lake	Trophic Classification	Annual Primary Productivity g C m^{2}yr^1
Waldo (Oregon)	Ultra-Oligotrophic	1
Char (N.W.T. Canadian Arctic)	Ultra-Oligotrophic	4
Castle (California)	Ultra-Oligotrophic	36
Lawrence (Michigan)	Oligotrophic	41
Lunzar Untersee (Austria)	Oligotrophic	45
Superior (USA-Canada; offshore)	Oligotrophic	50
Tahoe (Nevada-California)	Oligotrophic	70
George (New York)	Oligo-Mesotrophic	72
Huron (USA-Canada; offshore)	Oligotrophic	100
Flathead (Montana)	Oligo-Mesotrophic	137
Michigan (offshore stations)	Oligo-Mesotrophic	130-150
Clear (California)	Mesotrophic	160
Crooked (Indiana)	Mesotrophic	171
Ontario (USA-Canada)	Mesotrophic	180
Erie (USA-Canada; east basin)	Mesotrophic	ca. 180
Cayuga (New York)	Mesotrophic	ca. 200
North Lake (Texas)	Mesotrophic	ca. 200
Sammamish (Washington)	Mesotrophic	238
Esrom (Denmark) (1959)	Mesotrophic	260
Lac Leman (Switzerland) (1975)	Eutrophic	ca. 300
Minnetonka (Minnesota)	Eutrophic	ca. 300
Erie (USA-Canada; west basin)	Eutrophic	ca.310
Waco Reservoir (Texas)	Eutrophic	ca. 310
Washington (1971)	Mesotrophic	354
Wintergreen (Michigan)	Eutrophic	369
Sylvan (Indiana)	Eutrophic	570
Lanao (Philippines)	Eutrophic	620
Victoria (Africa)	Eutrophic	640
Washington (1963-64)	Eutrophic	766
Mendota (Wisconsin) (1965-66)	Eutrophic	1100

biomass is attended by a rise in the amount of decaying vegetation. Bacterial decomposition of this organic material requires large amounts of oxygen and depletes the lake supply of this vital gas. Certain species of blue-green algae that thrive in the high-nutrient, low-oxygen conditions become the dominant plant form; blooms of some species of blue-green algae have the side effect of releasing waste products toxic to other aquatic life. Many aquatic insect species are unable to survive and are replaced by other invertebrates tolerant of the altered conditions. Fish populations shift from trout and other coldwater species to rough fish better adapted to low dissolved oxygen levels. The eutrophic lake, the final product of this scenario, is foul-smelling, clouded with decaying organic matter, and unsafe for recreational or domestic use. The timespan for cultural eutrophication can often be measured in decades and is thus much more rapid than the natural eutrophication process.

Lake Erie of the Great Lakes chain is an infamous example of cultural eutrophication which resulted from the urban and industrial wastes from Detroit, Cleveland, and other densely populated shoreline communities. The Lake Erie example indicates that even large bodies of water are susceptible to the effects of nutrient pollution if the loading rate is high enough. During the last decade water quality and fish populations in Lake Erie have begun to show some improvement following the imposition of water pollution control measures; however, as long as excessive amounts of nutrients remain in circulation, the aquatic ecosystem will not fully recover from the effects of pollution.

Primary productivity (the amount of carbon incorporated from carbon dioxide gas by plants during photosynthesis) is commonly used to rank lakes on the scale from oligotrophy to eutrophy. This single measure reflects nutrient concentrations and suggests the type of biological community which will likely occur in a lake. Lakes of low productivity lie at the oligotrophic end of the scale, and can be expected to represent clear, coldwater systems. Lakes of high productivity are likely to have high loads of organic matter, low oxygen levels, and less desirable water quality. Primary productivity measurements also allow researchers to monitor trends in lake trophic status, a particularly important consideration if cultural activities are suspected to be contributing nutrients to the aquatic system.

Primary Productivity and Trophic Status of Flathead Lake

Primary productivity in the open, deep-water regions of Flathead Lake averages 137 grams of carbon per square meter of water surface per year ($137gC/m^2/yr$). In equivalent terms, this means that the algae in a square-ended column of water six feet on a side and extending from the lake surface to the bottom incorporates about one pound of carbon into algae during the course of a year. Lakewide, this carbon fixation totals roughly 140 million pounds annually.

Primary productivity figures are best utilized for comparison to productivity results obtained from lakes throughout the world. In this light, Flathead Lake ranks as relatively unproductive, with an average productivity comparable to Lake Michigan (Fig. 5.21). Lake Superior, the most isolated of the Great Lakes from cultural effects, is considerably less productive, while the polluted (eutrophic) west basin of Lake Erie exhibits twice the algal productivity of Flathead Lake. Lake Tahoe, second in surface area to Flathead Lake among western freshwater lakes, is only about half as productive as Flathead Lake.

The measured algal productivity places Flathead Lake above the normally accepted limits for oligotrophy and into the oligo-mesotrophic classification. Dissolved solid concentrations, dominant phytoplankton species, and water clarity also suggests that Flathead Lake is oligo-mesotrophic, while relatively low plankton counts and organic carbon concentrations are more typical of unproductive, oligotrophic conditions. Researchers appraising this combination of factors have concluded that Flathead Lake should properly be classified as oligo-mesotrophic.

Classification as oligo-mesotrophic signals a change from the long-held scientific perspective which has considered the deep, coldwater Flathead Lake as a classical example of oligotrophy. This intermediate trophic classification is important because it indicates that only slight additions of nutrients and resultant increases in plant productivity can be expected to cause noticeable changes in the biological communities. In this context, it is noteworthy that primary productivity in the eutrophic west basin of Lake Erie is only twice the current primary productivity of Flathead Lake.

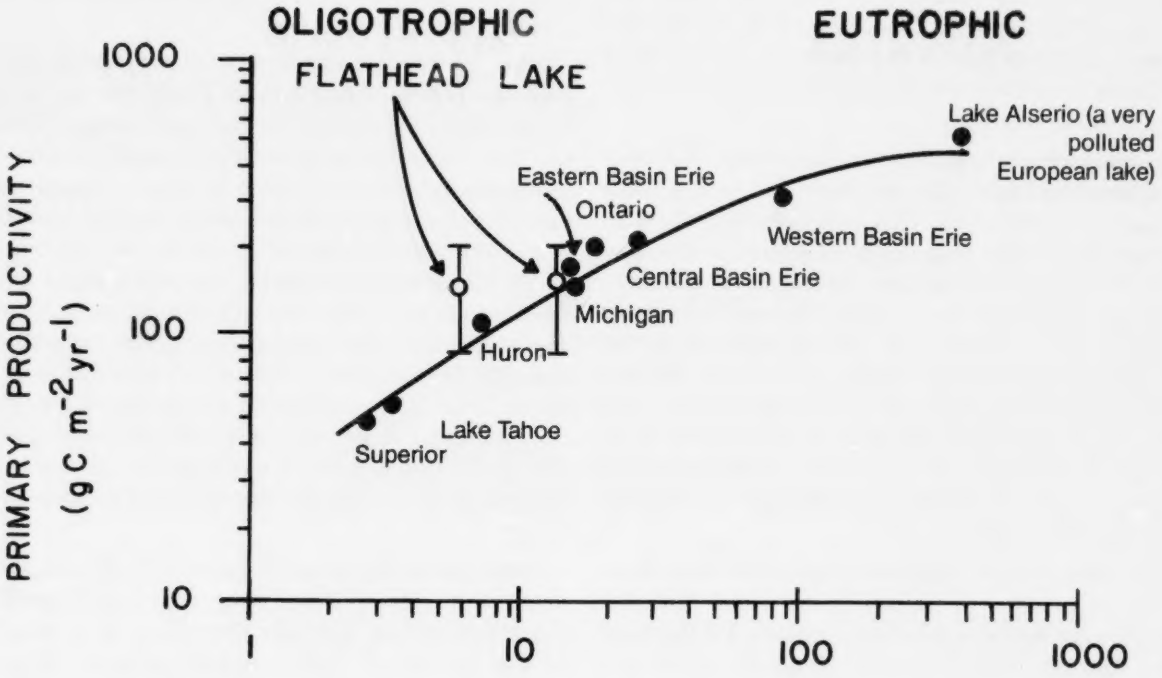
To assess the future of Flathead Lake, scientists working through the Flathead River Basin Environmental Impact Study sought to learn whether oligo-mesotrophic status means that the lake is becoming more productive due to man's activities. Unfortunately, earlier researchers lacked the sophisticated analytic techniques now available, so historical evidence on primary productivity is limited to algal population sampling. Although related to primary productivity, algal standing crops do not give a reliable measure of photosynthetic activity. Also, the larger mesh nets used for most previous collection missed the ultraplankton which are now known to dominate lake primary productivity. Because of the differences in current and historic research techniques, direct evidence is lacking on possible changes in the trophic status of Flathead Lake.

Calculations of nutrient budgets, however, have provided a powerful indirect method of assessing possible changes in the productivity of Flathead Lake. *This evidence clearly indicates that Flathead Lake has become more productive due to man-caused additions of nutrients. In other words, cultural eutrophication, with its potential for degraded water quality and altered biological communities, is underway in Flathead Lake.* The following discussion indicates how the nutrient phosphorus controls primary productivity in Flathead Lake and what changes have occurred to initiate the eutrophication process.

Phosphorus Dynamics

Forms of phosphorus. Phosphorus occurs in a variety of chemical forms. Organic (carbon-based) phosphorus compounds are incorporated in, or derived from, living matter. Genetic material, enzymes, and molecules which store, transfer, and release

FIGURE 5.21



Primary productivity of phytoplankton as a function of mean phosphorus concentration

energy are among the phosphorus-containing compounds that play critical roles in biological processes.

Inorganic phosphorus compounds are generally associated with certain mineral constituents of rocks and soils. Some inorganic phosphorus is tightly bound in the mineral form and is unavailable to the biological community. Other forms of inorganic phosphorus can be taken up by algae or bacteria through the action of enzymes or acids on the mineral substrate. These biologically available forms of phosphorus are commonly adsorbed to (i.e., attached to the surface of) fine sediment particles.

Phosphorus and primary productivity. In Flathead Lake, and in more than 80% of the north temperate lakes studied worldwide, the availability of phosphorus controls primary productivity. Additions of phosphorus will enhance algal photosynthesis, while removal of phosphorus will make a lake less productive.

The fertilizing action of phosphorus indicates that a shortage of phosphorus limits algal growth under normal conditions in most lakes. Phosphorus is thus a "limiting nutrient" to the Flathead Lake ecosystem; unlimited availability of phosphorus would allow algae to grow until another essential nutrient, such as nitrogen, was depleted enough to limit productivity.

Variations in the concentration of phosphorus in the lighted, upper layer correlate closely with algal productivity in Flathead Lake. During spring, vertical circulation of the water column keeps ample phosphorus available and stimulates a lakewide diatom bloom (Fig. 5.22). Algal productivity declines in mid-May as thermal stratification ends the mixing of lake waters, and the epilimnion phosphorus supply becomes exhausted. The entry of the Flathead River sediment increases the lake phosphorus supply and initiates a second pulse of algal growth, which lasts for about eight weeks. Settling of the sediments by late summer, however, causes another phosphorus deficit, and plant productivity drops sharply. Fall turnover remixes the lake water column, restoring phosphorus to the depleted upper layers. Despite cold water temperatures and reduced solar radiation through the winter, the continuous mixing of the lake water column maintains a supply of phosphorus in the epilimnion and primary productivity exhibits a slow, steady increase throughout the winter months.

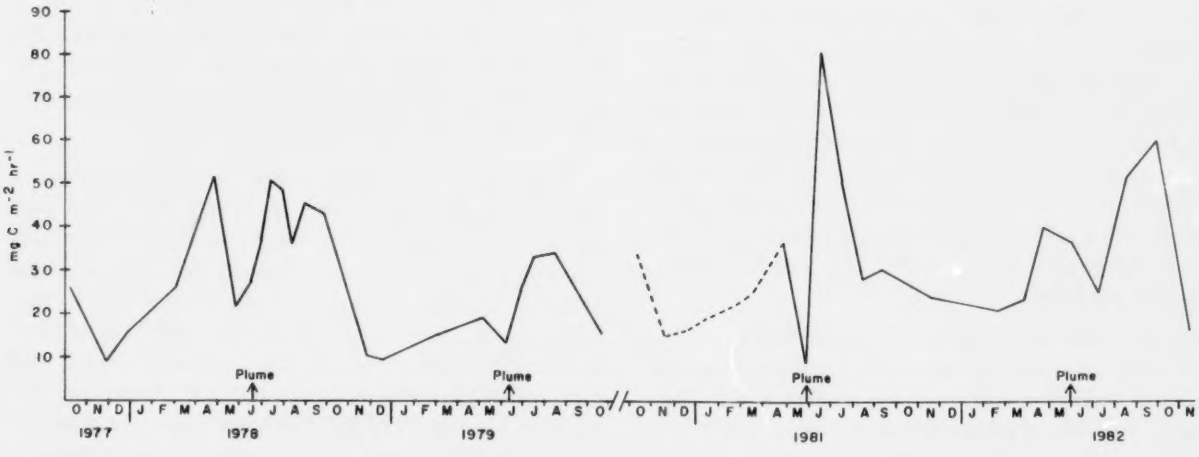
In years of above-normal spring runoff, Flathead Lake receives high sediment loads and thus greater amounts of phosphorus. This sediment-derived phosphorus can elevate primary productivity in the lake through summer and autumn, well after the sediment particles themselves have settled through the water column. Researchers are still investigating the dynamics of phosphorus exchange between the fine sediments and the lake biological communities; it is clear, however, that the duration and the extent of increased productivity by lake phytoplankton depends directly upon the amount of sediments discharged from the Flathead River.

The phosphorus budget of Flathead Lake. Fine silt and clay particles carried by the upper Flathead River are the major source of phosphorus for Flathead Lake. The silt- and clay-sized sediments, which originated from glacial scouring of the argillite mudstone, limestone and quartzite bedrock, occur in deep beds along portions of the North Fork, the Middle Fork, and their 4th order tributaries. Spring runoff undercuts these highly erosive banks, dropping sheets of fine sediments into the stream channels and leaving bare headwalls up to several hundred feet high. Logging, road-building, agriculture, and other land uses add to the sediment load in local areas of the Flathead drainage, but most of the riverborne sediments are generated by natural erosion.

Riverine concentrations of both suspended solids and phosphorus reach annual peaks during spring runoff. Biological assays on river sediments indicate that only about 6% of the phosphorus contained by the sediments is available for use by algae. Assays conducted on sediment samples taken directly from the eroding banks demonstrated considerable local variation in phosphorus availability but, surprisingly, in all samples less than 6% of the sediment phosphorus was available to stimulate algal growth. These results indicate that the availability of phosphorus from the sediments is somehow enhanced by weathering during river transport or that culturally derived organic phosphorus may be adsorbing to the surface of the sediment particles as they are being carried downstream.

Atmospheric deposition is the second greatest phosphorus source for Flathead Lake, with rainfall and dry particulate fallout annually depositing an estimated 25% of the annual Flathead Lake budget of biologically available phosphorus. Wind-blown soil and fertilizer, combustion products from wood burning and industrial activity, and natural organic matter, such as pollen, leaves, and insects, are the major contributors to the airborne phosphorus.

FIGURE 5.22



Primary productivity per square meter of the trophogenic zone at the midlake deep station of Flathead Lake, Montana, 1977-79, 1981.

Domestic sewage is the most important cultural source of phosphorus. The major sewage treatment facilities remove sludge and bacteria, but do not eliminate dissolved phosphorus. The Kalispell sewage treatment plant on Ashley Creek and the Whitefish sewage treatment plant on the Whitefish River serve the greatest populations and discharge the largest amounts of organic phosphorus into the Flathead drainage. The Columbia Falls and Bigfork sewage facilities are also important point sources of phosphorus. Phosphorus compounds in sewage effluent derive primarily from detergents and human wastes. These organic phosphorus compounds are highly reactive in the lake environment, fertilizing the growth of algae and other plants.

Residential septic systems on the Flathead Lake shoreline and in communities such as Evergreen along the river flood plain are believed to add to the regional phosphorus load, but measurements are lacking. Soil particles have a tremendous capacity to adsorb phosphorus, and properly designed septic systems will not generally contribute phosphorus to the groundwater or nearby rivers or lakes. Septic systems built in locations with high water tables or in extensive gravel deposits, however, may discharge phosphorus into the aquatic system.

Domestic sewage currently supplies 17% of the biologically available phosphorus in the Flathead Lake drainage. Other man-caused sources, including excess sediments released by forest practices, particulate fallout from combustion, and runoff from fertilized agricultural fields, are conservatively estimated to contribute another 10% of the biologically active phosphorus load. Thus, taken together, culturally derived sources account for approximately 27% of the reactive phosphorus in Flathead Lake.

Bay productivity. The effects of cultural additions of phosphorus are most evident in the bays of Flathead Lake. Bays generally support the densest residential and commercial development, and hence receive the greatest nutrient inputs. Moreover, bays are sheltered from lake currents, so local nutrient concentrations are not readily diluted.

Simultaneous measurements from a mid-lake station and seven bay locations revealed algal productivity in the bays was up to twice as high as in the open-water region. Thick algae mats occur on the bottoms of some bays, presumably as a result of the increased nutrient availability. Although historic conditions are not well documented, some residents along the lakeshore report that these algal mats did not exist as little as 10 to 15 years ago. Additionally, analysis of lake bottom sediments demonstrates higher concentrations of zinc near populated bays. The zinc is probably derived from sewage pipe, indicating some sewage effluent with associated nutrient loads, is apparently entering the lake from shoreline communities.

Sediment Geochemistry

Budget calculations indicate that only half of the phosphorus entering Flathead Lake is discharged at the lake outlet (Table 5.8). The remainder, about 67

TABLE 5.8

Mass Balance Budget for Phosphorus Flathead Lake, Montana

INFLUENT	H_2OX $10^9m^3yr^{1}$	x [P] mg m^3	Total [P] MT yr^{1}	%
Flathead River-Holt	8.783	8.6	75.53	64
Swan River-Bigfork	1.217	8.1	9.86	8
Bigfork Sewage	.000,069	6,400.0	1.08	1
Yellow Bay Sewage	.000,006	—	.02	
Bulk Precipitation	0.236	127.0	29.97	25
Shoreline Drainage	0.152	—	1.72	1
INFLUENT TOTAL			118.18	
EFFLUENT				
Flathead River-Polson	10.359	5.9	61.12	52
EFFLUENT TOTAL			61.12	

metric tons a year, settles to the bottom of the lake. Most of the phosphorus retained in the lake is derived from the clay particles carried by the Flathead River during spring runoff.

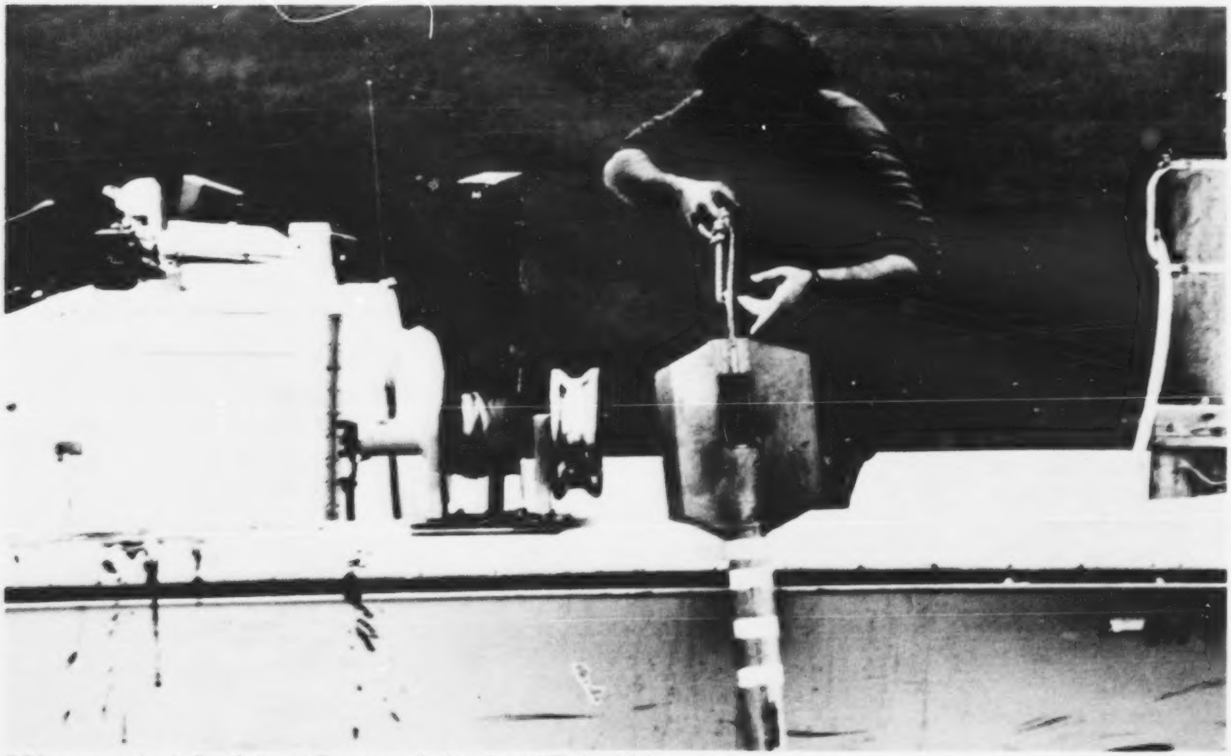
An examination of the sedimentation process provides insight into both the geologic history of Flathead Lake and the dynamics of phosphorus cycling. Research on lake bottom chemistry also shows how the bottom sediments function as a tremendous phosphorus storehouse which, under certain conditions, could release this nutrient with devastating impacts on water quality and the biological community of Flathead Lake.

Sedimentary history of Flathead Lake. Since the final retreat of the glaciers 10,000 to 14,000 years ago, Flathead Lake has experienced an annual cycle of a sediment-laden spring plume followed by rapid summer growth of phytoplankton. Settling of these particles has resulted in alternating layers of inorganic sediment and organic algae deposits on the lake bottom. These layers are identifiable in core samples, with light-colored layers representing sediment accumulations and thinner, dark layers consisting of decayed organic material.

Along the western shelf of the lake, this accumulation of regular sediment layers reaches a depth of 20 feet, reflecting an average deposition of 0.5 millimeters of sediment per year. In mid-lake regions, which receive smaller amounts of riverborne sediments, annual accumulations average 0.3 mm for a total sediment depth of 12 feet since the glacial period.

The relative uniformity of lake bottom sediment cores indicates that few major changes have occurred in the Flathead region since the ice age. The cores do contain some exceptionally thick organic deposits, evidence of a relatively warm period with greater algal growth following the glacial retreat. Thick bands of sediments from about 500 years ago testify to a wetter, cooler climate that increased the erosion and deposition of inorganic sediment in the Flathead drainage. The volcanic eruption of Mt. Mazama, which formed Crater Lake, Oregon, approximately 6,700 years ago, is marked by a dark ash layer at depths of 6 to 11 feet below the surface of the lake bottom sediments.

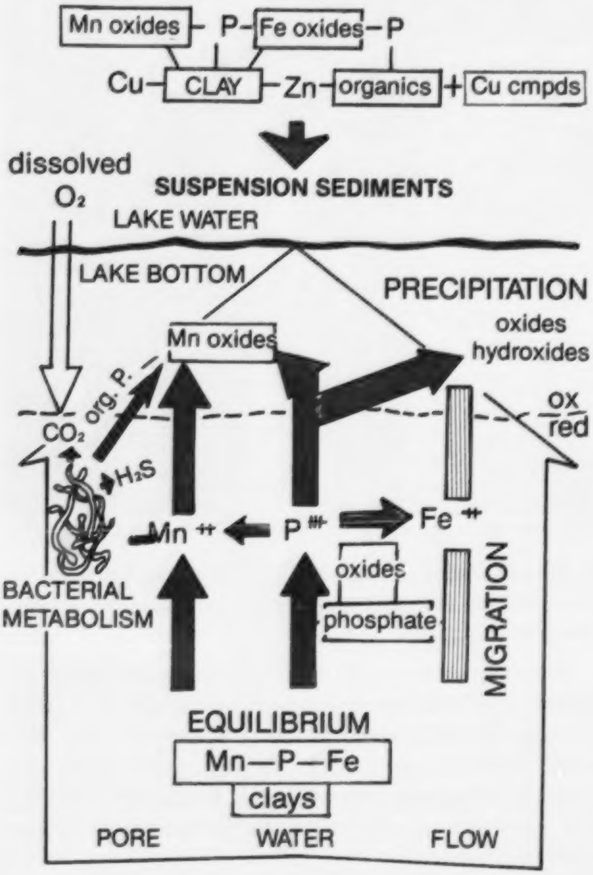
Sediment chemistry. Lake bottom profiles reveal that a one-centimeter-thick, light-orange layer caps the sediment surface. This top layer of sediments is permeated by lake water, which exhibits the high dissolved oxygen content typical of the overlying water column. Just below the oxidized sediments is a dark-



J. Moore preparing to drop bottom sediment sampler from boat in Flathead Lake brown sediment layer. This layer has a very low oxygen content, resulting from the action of the bacteria that exhaust the oxygen supply during the decomposition of organic compounds. Differences in the chemical environments between the upper, oxidized layer and the underlying, oxygen-poor layer (termed the "anaerobic" or "reduced" layer) have major impacts on phosphorus dynamics.

The fine clay particles in the sediment plume carry iron and manganese to the lake bottom, and these metals are largely responsible for binding inorganic phosphorus. In the oxygen-poor waters of the reduced layer, iron and manganese lose their affinity for the surface of the clay particles and enter solution as positively charged ions. Inorganic phosphorus similarly breaks its bonds with the iron and manganese, joining these two metals as dissolved constituents of the "pore water" (i.e., the water which fills the spaces, or pores, within the lake bottom sediments) (Fig. 5.23).

FIGURE 5.23
Dynamics of Phosphorus in Bottom Sediments of Flathead Lake



The pore water flows upward at a rate of about one-half millimeter per year, the result of the accumulating sediment layers squeezing water up through the loosely compacted surface sediments. The slow pore water flow carries disolved phosphorus, manganese and, to a much lesser extent, iron, into the oxidized surface layer of sediments. Here, the presence of oxygen causes the metal ions to precipitate (become undissolved) and reattach to the clay sediment particles. Phosphorus follows suit, and again becomes tightly bound to iron and manganese.

The gradual upward migration of ions concentrates phosphorus in the oxidized surface centimeter of Flathead Lake sediments. The average inorganic phosphorus content of the oxidized layer is 23% greater than the phosphorus concentrations in the reduced sediment layers. Magnesium concentrations are twice as great in the surface sediments than in the underlying layer, while iron, less mobile than the other ions, does not show a significant difference in concentrations between the oxidized and reduced sediments.

Sediment phosphorus and potential eutrophication of Flathead Lake. The research reviewed above reveals three findings of primary importance to the sediment chemistry of Flathead Lake:

••Lake bottom sediments contain large amounts of phosphorus which is concentrated in the surface, centimeter-thick layer.

••This thin, oxidized sediment layer allows dissolved phosphorus to precipitate onto clay particles and thus prevents phosphorus from entering the lake water column.

••The decomposition of organic materials by bacteria drives the chemical system by exhausting the oxygen supply of the reduced layer and mobilizing phosphorus and metal ions.

Based on these findings, researchers have determined what the future might hold for Flathead Lake if cultural additions of phoshorus continue to increase. The hypothetical sequence of events underscores the possibility of eutrophication of the lake due to the release of phosphorus from the bottom sediments.

The first step in this scenario involves a significant increase in the amount of biologically reactive phosphorus available to algae in Flathead Lake. This step simply requires a continuation of recent trends, which have demonstrated dramatic increases in phosphorus loading to the lake as the regional population has grown. Increased phosphorus would stimulate algal productivity and increase the amount of organic matter settling to the lake bottom. Bacterial activity within the sediments would rise, and oxygen levels would consequently decline. If the addition of organic matter were great enough, the presently oxidized top layer of sediments could lose all of its oxygen (become anaerobic). In this event, phosphorus migrating upward from the reduced sediments would no longer be re-adsorbed to the surface of clay particles; rather, the dissolved phosphorus would flow into the lake water.

The result would be a self-perpetuating chain reaction, with the phosphorus stimulating more algal production and causing more organic accumulation and decomposition on the lake floor. This, in turn, would further deplete oxygen from the bottom sediments and the overlying water. More phosphorus would be released into the lake to support more algal growth, and rapid eutrophication would be underway.

Anaerobic conditions on the lake bottom have caused the release of phosphorus from sediments in Lake Erie and in numerous other lakes undergoing cultural eutrophication. In Flathead Lake, the poorly circulated bays ringed by shoreline development are most susceptible to the potential problem of phosphorus release from the sediments. Some bays already have higher rates of primary productivity than midlake regions, and thus have more decomposing algae on the substrate. Increased shoreline additions of phosphorus, perhaps coupled with greater Flathead River discharges of culturally derived phosphorus, could significantly accelerate algal productivity in the bays and initiate the cycle leading to the release of sediment phosphorus. The results could include locally severe algae blooms and degraded water quality.

The magnitude of the potential problem can be appreciated by calculating the phosphorus concentration that would result if all of the sediment phosphorus were released into the Flathead Lake bays through the imposition of anaerobic conditions in the sediments. In Woods Bay, for example, the top oxidized centimeter of the lake bottom sediments contains 68 metric tons of potentially extractable, inorganic phosphorus. Release of this phosphorus would raise the phosphorus concentration in the bay to 400 micrograms/litter (ug.1). This concentration is over 70 times the average Flathead Lake phosphorus concentration of 5.4 ug/1, and well in excess of the concentration needed to cause eutrophication. Similar calculations indicate that anaerobic sediments in Yellow Bay and Somers Bay would yield even greater phosphorus concentrations than in Woods Bay. Although chemical constraints would probably keep some of the phosphorus in the sediments, if only 10% of the extractable phosphorus were released, rapid and extreme eutrophication would result.

B. K. Ellis removes primary productivity incubation racks from midlake.

The natural reservoir of phosphorus in the lake sediments thus represents a potential cause of drastic changes in the trophic status of Flathead Lake. Nutrient additions into the lake through human activities could trigger these changes, resulting in the loss of the clean water resource that gives Flathead Lake its exceptional values.

Modeling Productivity and Phosphorus Dynamics in Flathead Lake

Phosphorus budget calculations and primary productivity measurements demonstrate conclusively that Flathead Lake has become more productive due to man's activities in adding nutrients to the aquatic system. An estimated 27% of the annual phosphorus load now comes from cultural sources, with treated domestic sewage effluent discharged by cities along the upper Flathead River system responsible for most of the phosphorus enrichment. In a phosphorus-limited system such as Flathead Lake, the addition of biologically available phosphorus necessarily stimulates algal growth; elevated levels of primary productivity by algae in bay locations confirm the effects of nutrient loading on lake productivity.

Water quality in Flathead Lake, however, remains relatively pristine, and no dramatic changes in the lake's biological communities have been documented. The most noticeable effect of the increase in primary productivity is a reported reduction in water clarity due to increased organic particulates from algae, although historical conditions are not well documented.

To gain insight on how phosphorus is cycled within the Flathead Lake ecosystem, researchers developed a computer model to simulate the lake environment. Using the model, researchers can select a phosphorus loading rate for the lake and, in response, the model will predict the resulting primary productivity in the lake and the amount of phosphorus contained in each of four biological components (phytoplankton, zooplankton, organic detritus, and available nutrients). The modeling results were in close agreement with the values actually measured in Flathead Lake, thus verifying the validity of the model as a tool to assess how phosphorus loading will affect the lake ecosystem.

Researchers conducted simulations endowing the lake with varying phosphorus loads, ranging from one-half to twice present levels (Table 5.9). A phosphorus load 80% of present levels approximately simulates phosphorus levels in the lake in the absence of phosphorus inputs from community sewage treatment plants; the resulting primary productivity of the lake decreased by 10% with this reduced phosphorus budget. Simulations with an increase of 50% over current phosphorus loading resulted in a 40% increase in primary productivity, which would constitute significantly more eutrophic conditions than presently exist in Flathead Lake. Researchers have recently drafted a proposal to model the amount of phosphorus loading and attendant primary productivity that would lead to the release of phosphorus from the lake bottom sediments. When available, this information should establish a critical level of phosphorus loading for Flathead Lake.

The model also indicated the importance of the timing of phosphorus additions to Flathead Lake. Presently the lake receives a large share of its phosphorus in the form of suspended sediments during the runoff period. During the remainder of the year, the lake receives a relatively low nutrient input. Addition of phosphorus during the low-flow, low-nutrient season has a strong potential to alter the phytoplankton community, favoring species adapted to higher phosphorus availability. These species include some large blue-green algae which can undergo rapid population increases and which can degrade water quality through their own decomposition or through the release of toxic waste products. Land disturbances which add fine, phosphorus-containing sediments to the river system and thus to the lake year-round would have a high potential to degrade water quality in Flathead Lake.

While phosphorus loading from sources outside the lake plays the major role in controlling primary productivity, biological processes in the lake fine-tune productivity by recycling phosphorus and maintaining an available supply of this crucial nutrient. At any given time, nearly all of the biologically usable phosphorus is incorporated into plant or animal tissue. The living components, however, return phosphorus to the water, either through death and decomposition, excre-

TABLE 5.9

Simulated Impact of Phosphorus Loading on Primary Productivity

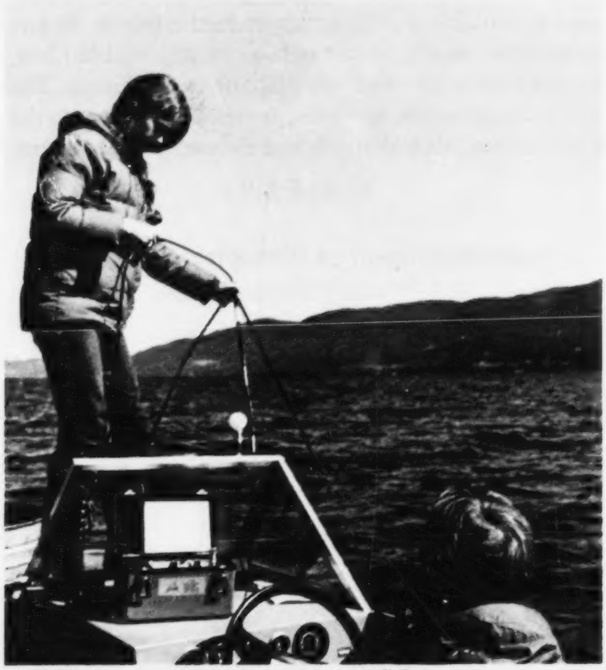
% Current Phosphorus Load	Primary Production* grams C/m²/yr.
50%	76.9
80%	94.2
100%	105.3
150%	146.0
200%	194.2

*Converted to carbon by assuming a carbon to phosphorus ratio of 106:1

tion of wastes by zooplankton and fish, or "leakage" of organic compounds into the water by algae. The rate of return of phosphorus to the aquatic system influences the level of primary productivity. For example, if much of the phosphorus is tied up in long-lived fish, little will be available for algae to use. Alternatively, if phosphorus is rapidly cycled through microoganisms and then returned to the water, a good supply of phosphorus will be continually available to be picked up by algae.

Simulation modeling indicated that zooplankton play a major role in recycling phosphorus. The zooplankters eat algae and organic detritus and then excrete the phosphorus-containing waste products into the water. Zooplankton excretion returns about 45% of all the phosphorus that is recycled in the lake environment; leakage of organic compounds from phytoplankton accounts for another 31% of phosphorus cycling.

Significantly, small zooplankters recycle phosphorus into the water faster than do larger zooplankters; thus the greater the relative abundance of small zooplankters, the greater algal productivity will be. Predation by fish removes the larger zooplankters and results in a smaller average size within the zooplankton community. This, in turn, leads to greater rates of phosphorus recycling, more phosphorus in the algae, and higher productivity.



B. K. Ellis prepares to lower light meter at midlake

The above discussion indicates that fish can play a role in increasing the productivity of Flathead Lake; however, it is important to emphasize that phosphorus recycling typically contributes only about 10% of the phosphorus available to the biological communities. Phosphorus loading from external sources, such as the Flathead and Swan river inflows, accounts for the other 90% of the phosphorus load. Management of these phosphorus inputs is by far the most effective way to retain low primary productivity and to conserve the high water quality in Flathead Lake.

Monitoring the Lake Ecosystem

The five-year research effort conducted through the Flathead River Basin Environmental Impact Study indicates that Flathead Lake maintains very good water quality, but that the lake is undergoing adverse changes. The documented increases in phosphorus loading and algal productivity—and the specter of potential eutrophication with degraded water quality and altered biological communities—underscore the importance of carefully monitoring the Flathead Lake ecosystem. The key elements of a detailed monthly program, as proposed by researchers from the University of Montana Biological Station at Yellow Bay, include monitoring:

*the amount of phosphorus entering Flathead Lake at the mouths of the Flathead and Swan rivers,

*the amount of phosphorus discharged from Flathead Lake at the outlet near Polson,

*the amount of phosphorus in precipitation and dryfall to determine how much phosphorus is entering Flathead Lake from the air,

*the concentration of phosphorus in the water at the Narrows above Polson and at two mid-lake stations,

*the rate of primary productivity by algae at various depths at a mid-lake station, and

*the inflow, outflow, and lake concentrations of nitrogen.

This monitoring program would document the nutrient loading of Flathead Lake and the effect phosphorus is having on algal productivity. Long-term trends in the lake status could thus be recognized, and important public policy decisions on land use and resource management could be addressed before the health of the lake is jeopardized.

Lone motorboater on Flathead Lake

FISHERIES

The Flathead Lake and River system is known for its high quality fishery resources. Tens of thousands of resident and visiting anglers test their skills in Flathead waters each year, and fish populations also support many valued wildlife species, including bald eagles, ospreys, and river otters. The recreational benefits of fishing, along with the local economic returns from the associated tourist trade, make vital contributions to the quality of life in the Flathead Basin.

Large bull trout and the ubiquitous westslope cutthroat trout are the most highly prized of the native fishes. Among the introduced species, most angler attention is directed to the abundant kokanee salmon, but a dedicated corps of fishermen also pursues the lake trout, or mackinaw, which attains weights up to a state record 42-pounder caught in Flathead Lake during 1979. An array of other native and introduced fish bring the Flathead drainage total to 22 species.

The fishery of the Flathead Basin depends upon the integrity of both Flathead Lake and the upper Flathead River system. Headwater streams provide the clean gravel and flowing water necessary for successful spawning and rearing of many species, while the lake offers a stable environment and more abundant food to permit the growth of adult fish. The fish link these distinct and widely separated habitats through seasonal migrations, a characteristic behavior of the introduced kokanee and of nine of the ten species native to Flathead waters. The rivers provide the corridors which make the migrations possible.

Self-sustaining populations of native fish and desirable introduced species indicate a finely balanced aquatic ecosystem. Natural physical, chemical, and biological processes, affecting water quality and quantity, energy and nutrient dynamics, and plant and animal populations must remain intact to support healthy fish populations. Environmental alterations which adversely affect any of these key processes will eventually cause declines in fish populations or changes in species composition.

Although historic fish populations in the Flathead system are poorly documented, population changes are known to have occurred as a result of man's activities. Dams on the South Fork, the Swan River, and at the outlet of Flathead Lake have changed flow and temperature regimes, several migration routes, and eliminated habitat. Migratory bull trout and cutthroat populations in Flathead Lake are believed to have declined substantially due to the effects of dams; both increases and decreases in populations of the introduced kokanee salmon have been related to different aspects of dam operation in the Flathead drainage.

The federal Wild and Scenic Rivers Act bars new dams on the forks of the Flathead River, and the only major new hydroelectric project now envisioned upstream from Flathead Lake is a possible reregulating dam on the already impacted lower South Fork. Numerous other resource development activities however, could adversely affect fish habitat and populations in the Flathead drainage. Large-scale coal mining, as proposed along the Canadian North Fork, could have severe impacts on habitat and water quality on waters near the mine site and in downstream reaches of the Flathead system. Accelerated logging, road-building, and activities related to oil and gas exploration and development have the potential to increase stream sediment loads in both the United States and Canadian portions of the Flathead Basin. Additionally, a number of so-called "micro-hydro" projects have been proposed for the Swan River drainage. These dams on small tributaries could disturb habitat and block migration routes for migratory fish.

Viewed on an individual basis, the development of a single new road, clearcut, drill site, or diversion dam might appear insignificant; however, the collective impacts of many small developments could jeopardize the fishery resource, especially if these developments proceed without adequate knowledge and consideration of fish requirements.

Fisheries research conducted through the Flathead River Basin Environmental Impact Study focused on the three most important game fish, bull trout, cutthroat trout, and kokanee salmon. Specific studies assessed migration patterns, habitat selection, food habits, and growth rates, and researchers paid particular attention to locating critical sites for spawning and population recruitment. Studies of kokanee spawning in the Flathead River system and Flathead Lake, funded by the federal Bureau of Reclamation and the Bonneville Power Administration, have been ongoing since 1979.

This research has thoroughly documented the 1978-1983 baseline of habitat conditions and fish abundance and distribution for bull trout, cutthroat trout, and kokanee salmon (Table 5.10 and 5.11). A detailed strategy for monitoring populations and habitat has also been devised to assure that future environmental alterations can be recognized and remedied before the fishery is damaged.

TABLE 5.10

Fish Distribution in Tributaries, North Fork of the Flathead River

Current information on fish distribution in North Fork tributaries. + = species present, — = species absent, ? = unknown, needs further study.

	Cutthroat		
	Adfluvial	Resident	Bull trout
Canyon	—	+	+[2]
McGinnis	+[1]	+	+[2]
Kimmerly	—	+	—
Big	+	+	+
Langford	+	+	+
Lookout	—	+	—
Elehehum	—	+	—
Hallowat	+	+	+
Werner	+	+	+
Skookoleel	+	+	+
Nicola	?	+	+
	—	+	+
Coal	+	+	+
Cyclone	+	+	+
Dead Horse	?	+	+
South Fork Coal	+	+	+
Mathias	+	+	+
Moran	+	+	+[3]
Hay	?	+	+[3]
Red Meadow	+	+	+
Moose	+	+	+
Whale	+	+	+
Shorty	+	+	+
Teepee	—	+	—
Trail	+	+	+
Ketchikan	+	+	—
Yakinikak	+	+	+
Antley	—	+	—
Nokio	—	+	—
Tuchuck	+	+	—
Colts	—	+	—

	Cutthroat trout		
	Adfluvial	Resident	Bull trout
Glacier Park			
Camas	+	+	—
Dutch	+	+	—
Anaconda	+	+	—
Logging	?	+	+
Quartz	?	+	+
Cummings	?	+	—
Bowman	?	+	—
Akokala	+	+	—
Parke	?	+	—
Long Bow	?	+	—
Ford	?	+	—
Kintla	?	+	—
Starvation	+	+	+
Kishenehn	+	+	+
Spruce	+	+	—
Sage	+	+	+
British Columbia			
Howell	+	+	+
Cabin	+	+	+
Cauldrey	+	+	+

[1] Cutthroat present below a falls located 1.34 km above mouth.

[2] Bulls present below a falls located .15 km above mouth.

[3] Bull trout in these tributaries may be resident bull trout. Access into these creeks is blocked during the fall months.

TABLE 5.11

Fish Distribution in Tributaries, Middle Fork of the Flathead River

Current information on fish distribution in Middle Fork tributaries, + = species present, — = species absent, * = migratory cutthroat, ? = unknown, needs further study.

	Cutthroat trout		
	Adfluvial	**Resident**	**Bull trout**
Charlie	?	+	+
Long	?	+	+
Bergsicker	?	+	+
Twenty—five Mile	?	+	—
Granite	*	+	+
Challenge	*	+	+
Dodge	*	+	+
Lake	?	+	+[1]
Miner	?	+	—
Morrison	*	+	+
Lodgepole	?	+	+
Whistler	?	+	+
Schafer	?	+	+
W. Fork Schafer	?	+	—
Dolly Varden	?	+	+
Argosy	?	+	+
Calbic	?	+	+
Cox	?	+	—
Clack	?	+	+
Bowl	?	+	+
Basin	?	+	+
Strawberry	?	+	+
E. Fork	?	+	+
Strawberry Trail	?	+	+
S. Fork Trail	?	+	—
Gateway	?	+	+

	Cutthroat trout			Eastern
	Adfluvial	**Resident**	**Bull trout**	**Brook trout**
Glacier Park				
McDonald	+	+	+	—
Lincoln	?	+	+	+
Walton	?	+	—	+
Harrison	?	+	+	+
Nyack	?	+	+	—
Coal	?	+	+	+
Pinchot	?	+	+	—
Muir	?	+	+[2]	—
Park	?	+	+	—
Ole	+	+	+	+
Forest Service				
Deerlick	—	—	+	+
Stanton	—	+	—	+
Tunnel	—	+	—	—
Paola	—	—	+	—
Dickey	—	—	—	+
Essex	?	+	—	—
Bear	*	+	+	+
Geifer	?	+	+	+
Skyland	?	+	+	—

[1] Bull trout were present below the falls.

[2] One mature bull trout and no juvenile bull trout were observed.

Bull Trout

The largest fish native to the Flathead drainage is the bull trout *(Salvelinus confluentis)*, which can reach lengths of over 30 inches and weights exceeding 20 pounds. Bull trout have a limited distribution in river systems along the east and west slopes of the Rockies in southern Canada and in the northern United States. In the Flathead Basin, a significant population of bull trout utilizes Flathead Lake and its river and stream tributaries in the upper Flathead and Swan drainages.

Until 1981, the bull trout was classified together with the Dolly Varden trout *(Salvelinus malma)*; however, on the basis of geographic distribution, morphological differences, and growth characteristics, the bull trout of inland waters is now considered a separate species, isolated geographically and genetically from the similar-looking but smaller coastal Dolly Varden.

Historic status. The bull trout was an important seasonal food for western Montana Indians, who captured the fish on its fall spawning runs. During the early part of the twentieth century, white residents of the Flathead Basin blamed the bull trout for reducing the numbers of "more desirable" species, and efforts were made to eradicate local bull trout populations. A commercial net fishery was permitted in Flathead Lake during the 1910s.

Bull trout in Coal Creek a tributary to the North Fork of the Flathead River

Public attitudes changed during the following decades, and the bull trout came to be recognized as an important native game fish. Since 1953, many tributaries of the North and Middle forks have been closed to angling to protect the vulnerable spawners and to insure adequate reproduction, and anglers have been required to release bull trout shorter than 18 inches so these pre-spawners will be able to mature. Hungry Horse Dam eliminated the spawning run of bull trout from Flathead Lake into the South Fork, flooded many spawning streams, and halted the downstream movement of the remaining young fish in Hungry Horse Reservoir. The dam may have reduced bull trout populations in Flathead Lake by as much as half.

Based on harvest records and limited net sampling, populations of bull trout appear to have remained stable in Flathead Lake and its tributary river system during the past two decades. Trophy-sized bull trout are now highly sought after for sport and food by boating anglers in Flathead Lake and by shore fishermen and floaters along the larger rivers.

Present concerns about bull trout in the Flathead system center on the effects of natural resource development on important habitat. Protection of the tributary streams used by bull trout for spawning and rearing is recognized as a critical factor in maintaining bull trout populations in the Flathead drainage. Identification of these spawning and rearing sites received a high priority in the fisheries research conducted through the Flathead River Basin Environmental Impact Study.

Spawning migration. The bull trout population in the Flathead drainage is almost entirely adfluvial, meaning that adult fish live in lakes and migrate into tributaries to spawn. The annual upstream movement from Flathead Lake begins in May, when adult bull trout enter the lower Flathead River. During the next four months, these fish gradually move into the North and Middle fork drainages. Most bull trout arrive at their spawning grounds in North and Middle Fork tributaries during late summer. Spawning peaks in September and the fish then return downstream, arriving at Flathead Lake by the beginning of November. Similar spawning migrations occur between Swan Lake and tributaries of the Swan River and between Hungry Horse Reservoir into the upper South Fork drainage.

Bull trout cover large distances during their annual migration. Spawning areas on tributaries of the North Fork in British Columbia are located up to 150 miles from Flathead Lake. The minimum distance from Flathead Lake to known bull trout spawning sites is the 55 river miles to Big Creek in the North Fork.

Spawning behavior and site preference. Most spawning occurs during September, with the majority of activity concentrated in a two-week period each year. Several physical factors are probably important in triggering spawning behavior, including water temperature, day length, and streamflow. Water temperature may serve as the final cue to the bull trout to initiate redd construction, as groups of spawners holding in one tributary were observed to synchronously begin redd construction after an overnight cold front lowered water temperatures. Average daily maximum water temperatures during peak redd construction in Flathead tributaries were 46° to 48°, although spawning activity was observed in water temperatures as high as 54°.

Upon reaching the spawning grounds, each bull trout pair selects and defends a spawning territory. The spawning process begins as the female bull trout sweeps her tail up and down across the stream substrate, "cleaning" the gravels and scooping out a shallow depression on the stream bottom. The female deposits her eggs in this nest, or "redd", and the male spreads the sperm-containing milt over the eggs. Following fertilization, the female moves upstream of the redd and disturbs the fine gravel and sand substrate. These materials settle on the eggs, providing a six-inch-thick protective layer beneath which the eggs will incubate.

Bull trout redds average about 6.5 feet in length and 4 feet in width, based on measurements of more than 500 redds in tributaries of the North Fork (Table 5.12). Redds are constructed in smooth-flowing runs and tails of pools with water depths generally between 10 and 18 inches.

TABLE 5.12

Average measurements of bull trout redds in tributaries of the North Fork of Flathead River during 1980 and 1981.

Drainage	Year	Number of redds	Length	Width	Depth
Big Cr.	1980	15	2.3	1.3	.32
	1981	24	2.3	1.2	.42[1]
Hallawat Cr.	1980	8	2.0	1.0	.31
	1981	14	1.8	1.0	.32
Coal Cr.	1980	48	1.9	1.1	.26
	1981	30	1.7	1.0	.32
So. Fork Coal Cr.	1980	2	2.3	1.0	.31
	1981	24	1.8	1.0	.24
Mathias Cr.	1980	10	1.9	0.9	.30
	1981	10	1.6	1.0	.22
Red Meadow Cr.	1980	6	1.8	0.8	.31
	1981	19	1.9	1.1	.29
Whale Cr.	1980	47	1.9	1.2	.30
	1981	101	1.9	1.2	.435[1]
Shorty Cr.	1980	4	2.0	1.1	.19
	1981	17	1.9	1.2	.33[1]
Trail Cr.	1980	31	2.4	1.5	.33
	1981	82	2.4	1.4	.41[1]
MEAN	1980	171	2.1	1.1	.29
	1981	321	2.0	1.2	.28[2]

[1] Measured to the bottom of the depression (pit). All other depth measurements were measured at the front edge of the depression.

[2] Depth measurements measured to the bottom of the depression (pit) were not included.

Gravels from one-half to two inches in diameter are the predominant material in redds, and adjacent stream areas not selected for redds show a much higher percentage of larger materials. The loosely compacted gravels used for redd construction permit a steady flow of oxygenated water to the eggs during their six-month-long development.

Too much fine sediment in the redd materials would restrict the intragravel flow of water, reducing the transport of oxygen to, and metabolic wastes from, the developing embryos. Fine sediments can also prevent the recently hatched young fish, or fry, from emerging from the substrate into the stream; such entrapment soon causes the death of the fry. Biologists do not know what the critical level of fine sediments is for successful bull trout spawning.

Spawning females produce an average of 850 eggs per pound of body weight. This translated into 5,500 eggs per fish in a representative sample of 30 North Fork spawners with an average weight of 6.15 pounds and an average length of 25 inches.

Scale samples collected from 31 Middle Fork spawners during 1980 indicated that most (26) of these migratory bull trout were six or seven years old; the remainder were five- or eight-year-olds. The spawners in this sample had a mean length of 21 inches.

Redd distribution and abundance. The large size and light color (due to the clean appearance of the swept spawning gravel) of the redds, coupled with the low, clear autumn streamflow, make bull trout spawning sites highly visible to streamside observers. Counting redds thus provides an excellent method of determining the distribution and abundance of spawning bull trout.

About 466 miles of stream are accessible to bull trout during their upstream migration from Flathead Lake to the North Fork and Middle Fork drainages. During four years of extensive ground and aerial surveys, researchers located redds in 134 miles of streams, or 29% of the available water (Table 5.13). This limited distribution of spawning sites indicates that only specific sites within a select number of streams provide the spawning habitat requirements for bull trout.

TABLE 5.13

Comparison of redd numbers by year for similar areas of the Middle and North forks of the Flathead River Drainages

Middle Fork of the Flathead River		Number of Redds			
Stream	Reach	1982	1981	1980	1979
Strawberry	I	12	15	4	*
	II	8	3	9	*
	III	1	—	—	*
	IV	18	3	4	*
Trail	I	30	26	31	*
Bowl	I	10	—	—	*
	II	—	5	19	*
	III	9	3	7	*
Clack	I	7	7	10	*
Schafer	I	17	12	10	15
Dolly Varden	I	36	31	21	20
Morrison	I	37	24	32	12
	II	13	—	—	—
	III	34	8	39	4
	IV	2	—	—	—
Lodgepole	I	23	18	14	32
Granite	I	34	14	34	12
Bear	II	23	12	9	*
Ole	II	51	19	19	*
Nyack	I	—	7	14	*
	II	23	—	—	*
Middle Fork subtotal		388	207	276	95
North Fork of the Flathead River					
North Fork River, B.C.		17	*	*	*
Cabin	I	—	2(3)	2	*
Howell	I	4	—	—	*
	II	99	72(3)	53(3)	*
Couldrey	II	9	23(3)	15(1)	*
Kishenehn	I	23	13(3)	16(2)	*
Sage	I	4	*	*	*
Squaw	I	5	*	*	*
Starvation	I	—	1(3)	1	*
Trail	I	100	44	31	35
Whale	I	55	19	12	10
	II	181	79	35	24
Shorty	I	56	17	4	33
Red Meadow	II	—	19	6	2
Coal	I	11	—	1	—
	II	64	29	47	40
	III	20	1	—	4
South Fork Coal	I	9	24	2	4
Mathias	I	17	10	10	2
Big	I	—	1	—	6
	II	45	23	15	6
Hallawat	I	31	13	8	2
North Fork subtotal		750	390	258	168
Total Flathead River Drainage		1138	597	534	263

*Not surveyed that year

(1) Results from survey by B.C. Research, Vancouver

(2) Combined U.S. and Canadian portions stream

(3) Counts made by helicopter

The highest redd counts occurred in 1982, when a total of 1,138 redds were located in the North and Middle fork tributaries. The 1981 count was second highest, with 704 redds. Biologists estimate that the 1981 redd count encompasses 85% of all redds in the U.S. portion of the North Fork, 75% of Middle Fork redds, and 70% of redds in the Canadian Flathead. Live-trapping of bull trout, in conjunction with redd counts, indicated that an average of 3.2 adult fish enter a tributary for each redd constructed during the spawning season. Based on these figures, the number of spawning bull trout in the Flathead River system during 1981 is estimated to be between 2,500 and 3,050. Similar calculations yield a population estimate of 2,400 to 2,925 spawners during 1980, and about 4,730 to 5,770 spawners for 1982.

The distribution of redds in tributary streams was consistent from year to year. Howell, Trail, Whale, and Coal creeks ranked as the top four spawning streams in the North Fork during each year these streams were surveyed. Among Middle Fork tributaries, Morrison, Trail, Dolly Varden, Granite, and Ole creeks generally held the most redds. Bull trout redds were located in 16 streams in the North Fork drainage and 14 streams in the Middle Fork drainage.

The Whale Creek drainage of the North Fork contained 284 bull trout redds during the fall of 1982, by far the most redds found in any stream in the Flathead drainage. This total greatly exceeded the 118 redds observed in Whale Creek and its tributaries during 1981, and was indicative of the increase in spawners throughout the Flathead drainage. Biologists speculate the high return of mature bull trout may have resulted from good flows and favorable incubation conditions in the tributaries five to seven years earlier (when most of the 1982 spawners were themselves produced), combined with a reduced angler limit from two to one fish per day.

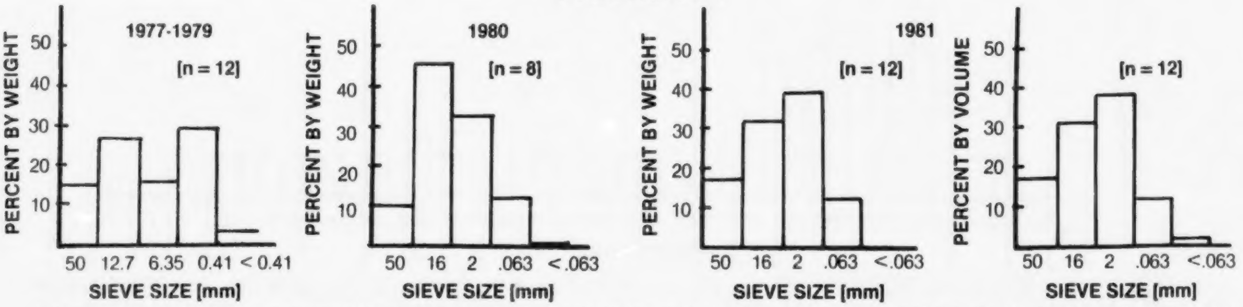
During 1982, 21% (156 of 736) of all redds in the North Fork drainage were located in Canada; during 1981, 31% (144 of 467) of the North Fork redds were in Canada. A single reach of Howell Creek near the proposed coal mine site accounted for 103 and 72 redds, respectively, during 1982 and 1981. Howell Creek redds consistently make up about 10% of the annual bull trout spawning activity observed in the entire Flathead Lake bull trout population. Initial plans for the open-pit coal mine development at the Cabin Creek-Howell Creek site called for the diversion of Howell Creek, an action which would have eliminated this important population segment. This proposal has been changed as a result of the concerns expressed by the State of Montana about impacts to the bull trout fishery; however, should mine development proceed, the close proximity of the mine to the creek jeopardizes both habitat and water quality, so the future of the Howell Creek spawning grounds is uncertain.

All bull trout spawning was confined to the tributary streams, with the exception of the Canadian North Fork which held an annual average of 20 redds. These redds were located in the 16-mile section between the international border and Squaw Creek.

The 3rd and 4th order tributaries to the North and Middle forks were most commonly used for spawning. Low channel gradient, the presence of nearby overhanging bank cover to shield the adult spawners, and high quality spawning substrate containing a relatively low amount of fine sediments in the stream substrate were all factors which apparently increase the suitability of a site for bull trout spawning (Fig. 5.24).

Juvenile bull trout. Juvenile bull trout were observed in 79 of the 159 intensively surveyed stream reaches in North and Middle fork tributaries. Population densities within occupied habitat were generally low. Observers saw an average of 1.5 fish for each 100 square meters (m^2) of stream surface, and numbers

FIGURE 5.24



Composite substrate composition of gravels collected from bull trout redds in North Fork tribuatries from 1977 to 1981. Percent composition by weight and volume are compared for 1981.

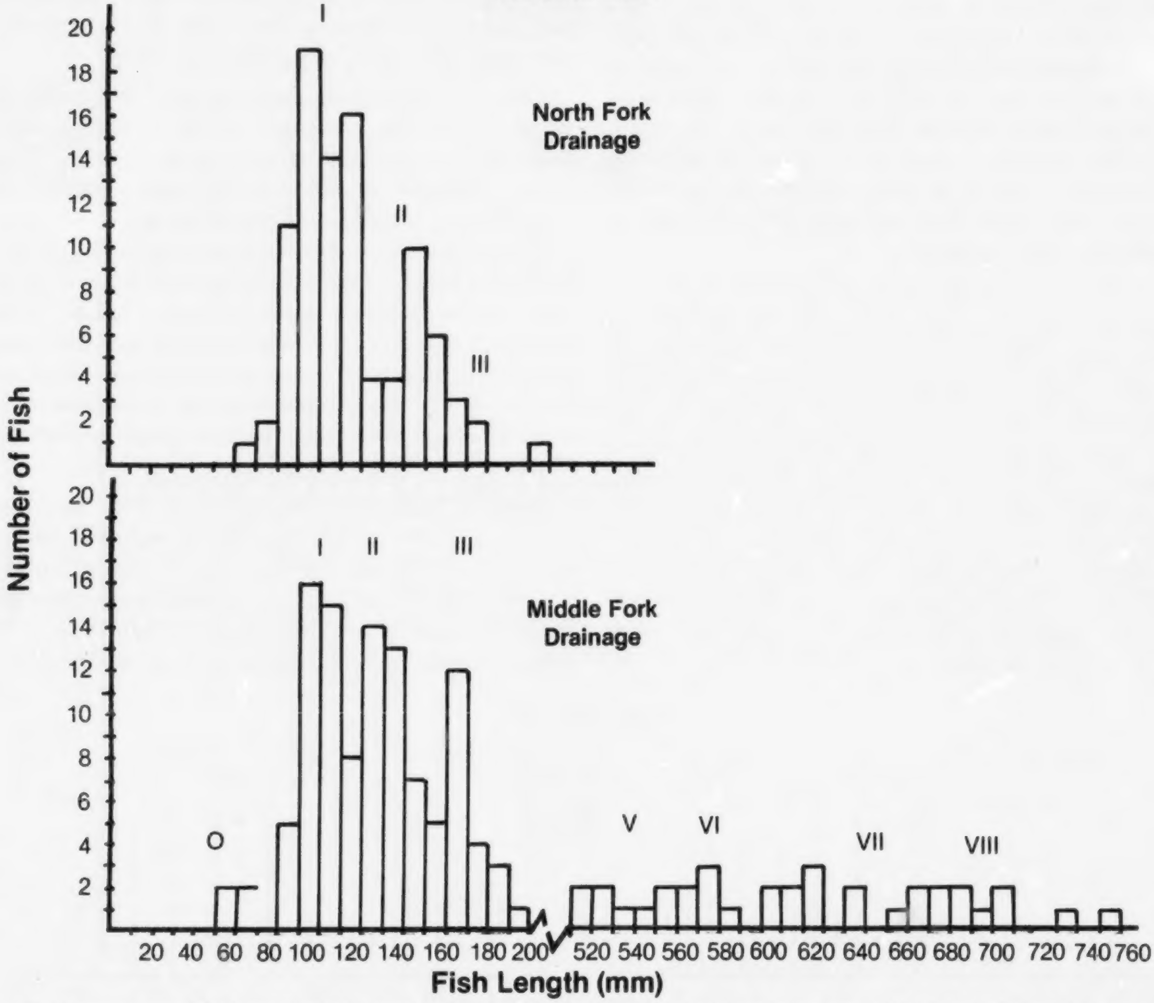
ranged up to 7.5 fish per 100 m^2. These counts, however, were obtained using a snorkeling technique which underestimates population size because of tendency of juvenile bull trout to hide amidst stream bottom cover. Twenty-two tributary stream reaches (7 in the North Fork drainage and 15 in the Middle Fork drainage) were identified as critical bull trout rearing habitat by virtue of their higher than average densities of juvenile fish. Juvenile bull trout densities were much lower in both the North and Middle forks than in their tributary streams.

Juvenile bull trout were closely associated with stream bottom cover in the form of woody debris and rocks. In addition, pool and run areas held relatively higher concentrations of young fish than did riffles.

Bull trout generally spend two or three years growing and developing in their natal streams. Some apparently move upstream to find suitable rearing habitat, as young fish have been found well upstream from areas where spawning occurs. Downstream emigration of juvenile bull trout, or smolts, begins during spring runoff and continues through the summer. Most smolts probably reach Flathead Lake by early fall.

Growth rates of juvenile bull trout in the tributary streams are extremely slow, a consequence of the short growing season, low nutrient levels, and low water temperatures. Bull trout in the tributaries grow slightly more than two inches per year (Fig. 5.25). The average three-year-old fish is seven inches long and weighs only two ounces.

FIGURE 5.25



Length frequency of 93 juvenile bull trout collected from North Fork tributaries and 103 juveniles and 35 adult bull trout collected from the Middle Fork of the Flathead River and tributaries in 1980.

Comparison of stomach contents with available food resources revealed that juvenile bull trout are opportunistic feeders. Mayfly nymphs and midge larvae are the most abundant aquatic insect species in the tributaries where bull trout rear, and these two insect orders are the most important invertebrates in the bull trout diet. Stonefly nymphs and caddisfly larvae both occur at much lower frequencies in the stream habitat and in the diet. Juvenile bull trout over 4½ inches in length will also feed on live fish.

Bull trout in Flathead Lake. Bull trout populations in Flathead Lake consist of smolts recently emigrated from Flathead River tributaries, subadult fish less than 18" in length, and mature fish of age five and older. Gill net results indicate that many adult bull trout do not undertake a spawning run each year.

Bull trout are widely distributed through the deep-water areas of Flathead Lake. The vertical distribution of bull trout is strongly influenced by water temperatures and prey distribution. During spring and fall when the lake water column is of a single temperature, nearly equal numbers of bull trout were taken in gill nets set between 10- and 45-foot depths and those set between 45- and 110-foot depths. Bull trout were more common in the cooler portions of the lake below 45 feet during the summer months.

Food habits of Flathead Lake bull trout. Fish were the dominant item in the diet of Flathead Lake bull trout and occurred in 91% (334 of 367) stomachs analyzed from 1979 through 1981 (Fig. 5.26). Three species of whitefish (lake, mountain, and pygmy) were the most important year-round prey of bull trout, followed in order of importance by yellow perch, kokanee salmon, and a wide variety of nongame species.

Significant seasonal variations in diet were apparent. Kokanee were the most important food item during spring. Bull trout appeared to be selectively feeding on kokanee at this time because kokanee had a considerably greater relative abundance in the diet than in gill net samples. During summer and fall, bull trout fed most heavily upon lake and mountain whitefish. Active selection for whitefish as prey may have occurred during the fall, when both northern squawfish and peamouth are abundant at the same depths as bull trout but were seldom eaten. A number of bull trout collected during summer had eaten the viscera and other parts of kokanee which had apparently been dropped overboard by fishermen cleaning their catch. Bull trout caught during October and November in the Flathead River just above the lake had fed extensively on pygmy whitefish. These five-inch-long fish concentrate near the mouth of the upper Flathead River during their fall spawning season, and bull trout had up to a dozen pygmy whitefish in their stomachs. Immature yellow perch, from 1½ to 2½ inches in length, were an important component of the winter diet of bull trout.

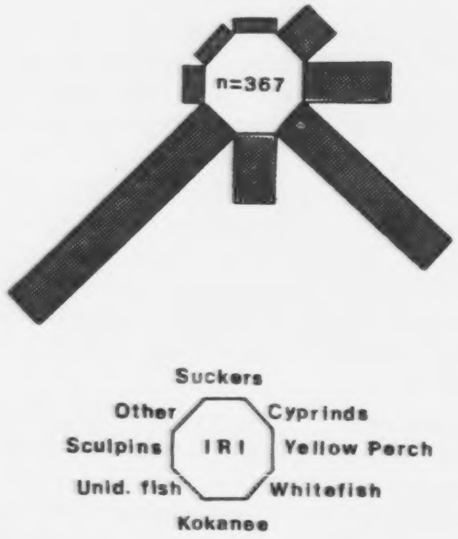
Bull trout size strongly influenced prey selection. The maximum length of prey taken by a given size class of bull trout averaged 43% of bull trout length. Bull trout longer than 22 inches fed almost exclusively on whitefish and kokanee, while three-inch-long slimy sculpins were the most important food for bull trout less than 12 inches in length. Aquatic and terrestrial insects constituted less than one percent of the prey weight, even among the smallest bull trout size classes.

Growth rates in Flathead Lake. Bull trout in Flathead Lake grow steadily, gaining about 3½ inches annually. Four 8-year-old bull trout collected during 1980-81 averaged about 25 inches in length, and a single 9-year-old fish measured 27 inches (Table 5.14).

FIGURE 5.26

Bull Trout
Food Habits

177 - 740 mm



Relative importance (Index of Relative Importance) of various forage fishes in the diet of bull trout collected from Flathead Lake during the years 1979-1981.

T. Weaver and B. Sheperd hauling in nets, Flathead Lake

A comparison of weight gain between juvenile bull trout in the tributaries and adult fish in Flathead Lake indicates the greater relative productivity of the lake than the stream environment for bull trout growth. Three-year-old juveniles in tributary rearing sites weigh about two ounces; during its first three years in Flathead Lake, a bull trout typically increases its weight 15-fold to the average six-year-old weight of two pounds. Weight gain accelerates in later years, and mature bull trout add about 2½ to 3 pounds per year in the lake, despite the tremendous energy drain of the six-month-long spawning migration.

Monitoring bull trout status. Life cycle studies in the Flathead drainage reveal that bull trout use very specific sites within a limited number of streams for spawning and for the rearing of juveniles. Maintaining healthy bull trout populations thus depends on the protection of these critical reaches.

Fisheries researchers have designed a detailed program to monitor bull trout numbers and habitat conditions to assure the future of this native species in the Flathead drainage. The monitoring program should be conducted annually so that any environmental or population changes can be detected in time for corrective action.

Continued redd counts are a basic element of the monitoring strategy. Specific reaches of four North Fork tributaries and eight Middle Fork tributaries are recommended for redd surveys each fall; these stream sections encompass the most heavily used spawning areas in the Flathead drainage. Redd counts will provide an indication of bull trout status and will reveal any local population changes which might be traced to either habitat alterations or harvest.

Electrofishing or snorkel counts are planned to determine the abundance of juvenile bull trout in 14 tributaries (seven on the North Fork and seven on the Middle Fork) to assess juvenile survival and the potential for bull trout recruitment to Flathead Lake.

Sampling of streambed composition is a third aspect of the bull trout monitoring program. As road construction, logging, and other development activities proceed in watersheds containing bull trout spawning grounds, the potential for stream sedimentation increases greatly. Researchers and managers from the Montana Department of Fish, Wildlife and Parks and the U.S. Forest Service are cooperating to monitor habitat conditions in the spawning streams and to assess the optimal substrate composition for bull trout spawning. Six stream sections in the North Fork and one tributary in the Middle Fork have potential for increased sedimentation from development and were selected for sediment monitoring.

Information on fish abundance, spawning sites, habitat features, and monitoring sections for both bull trout and cutthroat trout has been mapped in detail for the North Fork and Middle Fork drainages. These maps, based on five years of field research, represent an extremely valuable data base against which future conditions can be measured.

A final element of the bull trout monitoring program involves gill-net sampling in Flathead Lake to indicate relative bull trout abundance and growth rates.

T. Weaver and G. Michael electrofishing, Coal Creek

TABLE 5.14

Bull trout growth (millimeters) in various waters.

		Total length (mm) at annulus								
		I	II	III	IV	V	VI	VII	VIII	IX
Flathead Lake										
This study	mm	68	130	204	292	384	472	567	658	731
(1963-1981)	(n)	(929)	(929)	(926)	(851)	(601)	(290)	(102)	(28)	(4)
Block (1955)	mm	76	150	234	335	457	566	691	780	—
	(n)	(80)	(51)	(44)	(43)	(41)	(31)	(15)	(1)	—
Rahrer (1963)	mm	71	140	208	323	452	594	724	876	—
	(n)	(289)	(289)	(245)	(203)	(80)	(14)	(1)		
North and Middle Fork	mm	72	108	140						
Flathead tributaries[a]	(n)	(196)	(97)	(16)						
Middle Fork Flathead[a]	mm	48	97	174	286	389	484	575	636	—
River	(n)	(122)	(83)	(41)	(31)	(31)	(29)	(14)	(3)	
Hungry Horse[b]	mm	72	144	225	324	429	513	594	671	—
Reservoir, 1953&1972	(n)	(212)	(212)	(185)	(130)	(60)	(28)	(5)	(3)	
Lake Koocanusa[c]	mm	67	123	212	309	390	482	518	—	—
	(n)	(162)	(162)	(157)	(96)	(37)	(11)	(1)		
Priest Lake[d]	mm	71	114	183	310	424	516	605	—	—
	(n)	(61)								
Upper Priest Lake[d]	mm	66	102	155	239	358	462	546	612	—
	(n)	(41)								

a/ Fraley et al. 1981
b/ Huston 1974
c/ May et al. (1979)
d/ Bjomn 1961

Cutthroat Trout

Westslope cutthroat trout *(Salmo clarki lewisi)* are native to the lakes and streams of western Montana, northern Idaho, southern Alberta, and parts of British Columbia and Saskatchewan. Westslope cutthroat have proven extremely intolerant of stream siltation caused by agricultural and forest practices and of competition from the introduced rainbow and brook trout. These factors have eliminated the westslope cutthroat from about 90% of the waters within its range, and this fish is now considered a "species of special concern" by the Montana Department of Fish, Wildlife and Parks.

Cutthroat populations in the upper Flathead drainage can be found in many lakes and in nearly every stream with enough holding water to support fish life, and the so-called "natives" provide an important recreational fishery for 6- to 16-inch fish. The numbers of cutthroat in Flathead Lake, however, have probably been reduced from historic levels by Bigfork Dam and Hungry Horse Dam, which isolated the lake from important spawning areas and thus from recruitment stocks of juvenile fish in the Swan River and the South Fork of the Flathead River.

Many cutthroat in the Flathead drainage are adfluvial migrants which undertake annual spawning runs from lakes into tributary streams. Adult cutthroat from Flathead Lake spawn in many of the same streams used by bull trout, thus exhibiting annual round-trip movements of up to 300 miles—a remarkable feat for fish which average about 14 inches in length. Other cutthroat are "fluvial", residing in the Swan River or the forks of the Flathead and entering tributaries to spawn. Still a third life cycle is displayed by "resident" cutthroat, which remain in their natal streams for growth, development, and spawning.

Adfluvial migration. Adult cutthroat trout (age four and older) from Flathead Lake begin entering the mouth of the Flathead River as early as November, and during the next several months these fish become distributed in the river between Flathead Lake and the mouth of the Stillwater River. This 23-mile-long section is backed up by lake waters maintained at artificially high levels by Kerr Dam, and has a very slow current.

With the beginning of spring runoff in April and early May, cutthroat move up the Flathead River and into the North and Middle forks. Arrival at the tributary spawning peaks from late May into early June. Redd excavation, and spawning follow the pattern described for bull trout.

After spawning, adult cutthroat move out of the upper basin, but the timing and duration of the return trip to Flathead Lake are not well known. Some cutthroats move very rapidly, as evidenced by a returning spawner tagged in Howell Creek, British Columbia, and recaptured 70 miles downstream below Columbia Falls on the following day.

A few tagged cutthroat displayed some unexpected movements. One fish from Howell Creek and another from Trail Creek in the North Fork drainage were later caught in Kintla Lake on the west slope of Glacier National Park. Another cutthroat tagged in Howell Creek swam downstream to Flathead Lake then moved up the Swan River east of Bigfork, a return movement totaling about 123 miles (Fig. 5.27).

The high water conditions typical of spawning season make cutthroat redds extremely difficult to locate. As a result, spawning populations cannot be readily estimated, as was possible for bull trout.

Researchers were able to measure 31 cutthroat redds in Middle Fork tributaries. The larger redds of the migratory fish averaged 40 inches by 18 inches, while those constructed by resident fish had linear dimensions about one-third smaller. The migratory fish which constructed these redds were probably fluvial, residing as adults in Granite Creek or the Middle Fork of the Flathead River. Redds were constructed on fine gravel substrates in waters averaging seven inches deep.

Abundance in the Flathead River system. Cutthroat trout were observed in 89 of 92 tributaries surveyed in the North and Middle fork drainages. In North Fork tributaries, densities averaged 10 fish per 100 square meters (m^2) of stream surface, and reached a maximum of 74 fish per 100 m^2. Tributaries of the Middle Fork averaged only 4 fish per 100 m^2, with slightly greater densities occurring in tributaries above Bear Creek. Thirty stream reaches (17 in the North Fork and 13 in the Middle Fork) had densities greater than 10 cutthroat per 100 m^2 and were classified as critical rearing habitat (Table 5.15).

River-dwelling, or fluvial, cutthroat are relatively uncommon in the Flathead system, although sections of the South Fork and the Middle Fork above Bear Creek do have good fluvial cutthroat populations. Very few fish younger than age two were observed in either the North or Middle forks, indicating that young cutthroat rear almost exclusively in the tributaries.

Habitat features and cutthroat populations. Available cover is the single most important habitat feature influencing cutthroat densities in tributary streams. Overhanging riparian vegetation and stream depth and turbulence hide fish from potential predators, while logs and large instream rocks offer relief from the current, as well as visibility protection. In general, researchers found that the more cover available in a tributary section, the greater the cutthroat trout populations.

TABLE 5.15

Critical Cutthroat Trout Rearing Streams

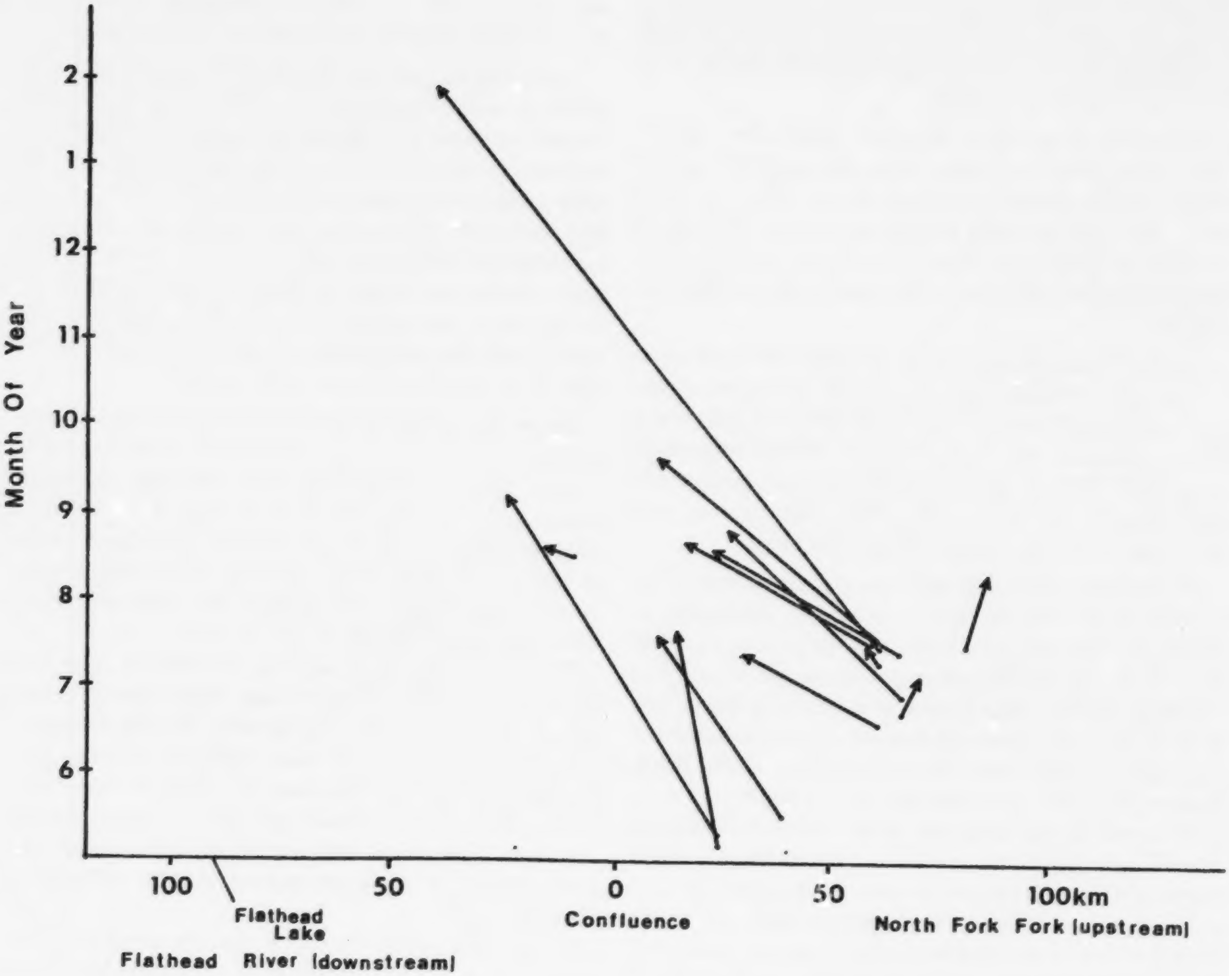
North Fork of the Flathead River Tributaries (17 reaches)

Lanford
Moose
Ketchikan
Moran
Cyclone
Tuchuck
Bowman
Red Meadow
Sage
Dutch
South Fork of Coal Creek

Middle Fork of the Flathead River Tributaries (13 reaches)

Walton
Muir
Essex
Gateway
Basin
Challenge
Twenty-five Mile
Argosy
Cox
East Fork of Strawberry Creek

FIGURE 5.27



Date and location of juvenile westslope cutthroat tagged (.) in the North Fork of the Flathead River and recaptured (→) at various points in the drainage. All movements are for fish tagged and recaptured within a six month period.

K. Pratt and T. Weaver electrofishing

Cutthroat population densities were also significantly influenced by stream size. The small 2nd order tributaries supported 12 cutthroats per 100 m^2 surface area, 3rd order streams hosted an average density of 6.8 fish, and the large 4th order streams (which generally contain less trout cover) averaged only 2.5 fish per 100 m^2.

Higher than average cutthroat densities were associated with streams containing moderate-sized materials in the substrate. Additionally, streams with more smooth-flowing runs and less riffle habitat supported more fish. Within a given stream section, pools held the majority of cutthroats. This relationship was strongest for three-year-old and older fish.

Emigration of juveniles. Juvenile cutthroats emigrating from rearing sites in Flathead tributaries to Flathead Lake are primarily two- and three-year-old fish. Most emigrating juveniles leave the tributaries during the high-water period and into July. These fish feed in the river system and move downstream slowly. Six-inch juvenile migrants are abundant in the North Fork during July and August. Most emigrating juveniles arrive in the Flathead River below Kalispell by late fall. Biologists do not yet understand what causes some cutthroat to remain in tributary streams for their entire lives and others to migrate downstream to the larger rivers or to Flathead Lake to spend their adult lives. Dispersal may relate to habitat availability; if holding areas are absent or already occupied by other fish, juvenile cutthroats may begin moving downstream until suitable habitat is encountered. For many fish, this emigration leads all the way to Flathead Lake. Genetics may also be a factor in determining which juvenile cutthroat will emigrate. Adult cutthroats, whether displaying resident, fluvial, or adfluvial life cycles, are believed to return to spawn in the same tributaries where they hatched and developed as juveniles.

Food habits. Cutthroat trout in the Flathead drainage feed on a wide range of aquatic and terrestrial insects. Diets reflect the availability of prey species in different habitats, as well as shifts in food preference among different size fish.

In tributary streams, cutthroat less than four inches in length feed most heavily on midge larvae and mayfly nymphs. These aquatic insects are the most abundant representatives of the stream bottom community and are readily available to juvenile fish. Small stonefly nymphs and caddis larvae are also eaten.

Cutthroat larger than four inches continue to depend on mayfly nymphs, but use of the tiny midge larvae declines. Caddis larvae increase substantially in importance in the diet among these larger fish, despite a relatively small caddis population in the tributary streams where the food habit studies were conducted. Three-year-old and older cutthroat also feed heavily on terrestrial insects which land or are blown onto the water surface. Ants, beetles, and spiders are the most common terrestrial insects in the diet of cutthroat in the tributary streams.

Westslope cutthroat trout in Flathead Lake also feed primarily on aquatic and terrestrial insects. During spring, the most important diet items are the midge pupae and adult midges which emerge in tremendous numbers from the bottom sediments as the lake warms in late March and April. Beetles, ants, bees, hemipterans (true bugs), and spiders are also commonly eaten by lake cutthroat during spring.

Winged insects dominate the summer and fall diets of cutthroats collected in the lake. Migratory cutthroat which moved into the slow-moving 23-mile section of the Flathead River between Kalispell and the lake during late October also fed on a wide variety of insects. The three largest species of zooplankton, *Daphnia, Epischura,* and *Leptodora,* comprised only four percent of the warm-season diet of cutthroat in Flathead Lake.

Insect availability drops off sharply during winter, and food intake by cutthroat is correspondingly reduced. Nearly two-thirds of the fish collected from the lake during winter had empty stomachs, and the average weight of stomach contents was 13 to 80 times less than that found during other seasons. Unlike cutthroat in Koocanusa Reservoir on the Kootenai River and in many lakes in the western United States, cutthroat trout in Flathead Lake are apparently unable to effectively utilize zooplankton as an alternative food source during winter when insects are unavailable. This feeding difference is probably related to the fact that populations of preferred zooplankton prey in Flathead Lake typically declined to negligible levels during the late Fall.

Cutthroat trout collected from the lower section of the upper Flathead River during winter fed on stonefly nymphs, mayfly nymphs and adult midges. The increased food consumption by these cutthroat relative to the fish which remain in the lake indicates that the movement into this river section several months prior to the spawning run may be a response to the greater winter food availability in Flathead River than in the Lake.

G. Michaels and T. Weaver measuring and weighing fish netted in Flathead Lake

Size and growth rates. Short growing seasons, low nutrient levels, and cool water temperatures severely limit the size of cutthroat trout in the streams of the Flathead drainage. Growth rates average less than two inches per year in small tributaries, and four- and five-year-old resident stream cutthroat generally range from 7- to 9-inches in length. Cutthroat which spend their adult lives in the forks of the Flathead grow somewhat more rapidly than those in the tributaries. Adult fluvial cutthroat commonly reach a size of 9 to 12 inches.

Cutthroat which migrate to Flathead Lake attain the greatest size and have the fastest growth rates of the populations in the upper Flathead drainage. Four-year-old lake cutthroat average 10 inches, while an eight-year-old fish was 16 inches long and weighed 1.4 pounds. Cutthroat trout in Flathead Lake do not reach sexual maturity until reaching approximately 14 inches in length, generally at age five or six.

Cutthroat trout taken from Flathead Lake during the 1980-81 sampling period exhibit similar growth rates to those reported during the 1960s. Popular articles and personal recollections of area residents indicate that cutthroat may have attained larger sizes in Flathead Lake during the early part of this century than they do today. The postulated reduction in fish size may relate to the lower fishing pressure during earlier decades which led to greater populations of older, larger fish. Alternatively, habitat changes may have occurred to have reduced cutthroat food availability in Flathead Lake. Since the construction of Kerr Dam in 1938 artificially high lake levels have eroded banks and eliminated marshlands in the Flathead River delta and along the lakeshore; these areas may have provided feeding habitat for cutthroat.

Distribution in Flathead Lake. Cutthroat trout are distributed throughout Flathead Lake, with highest numbers taken by gill-net sampling in the northeast portion near Bigfork. A proportion of the lake cutthroat enter the lower portion of the Flathead River during late fall and early winter. This movement may be a spawning-run "false start", triggered by relatively warm flow releases from Hungry Horse Dam which incorrectly indicate to the cutthroat that spring warming is underway. Alternatively, the late fall-early winter movement by cutthroat into the Flathead River may simply be a response to the increased food availability in the river compared to the lake during this season.

Monitoring cutthroat trout populations. Cutthroat trout present a number of difficulties for researchers wishing to monitor population status. The migration of adfluvial cutthroat from Flathead Lake into the tributaries occurs during spring runoff when electrofishing or other census techniques are most difficult to employ. Moreover, the high water obscures the cutthroat redds so counts, successfully used for bull trout, have little application for cutthroat. Finally, tributary populations of cutthroat in most streams contain a mix of resident fish, young fluvial fish that will move to the rivers for their adult life, and juvenile adfluvial fish that will emigrate to Flathead Lake for growth and development. These separate populations cannot be sorted out by observers.

Gill-net sampling proposed for Flathead Lake offers a technique to assess cutthroat growth rates, food habits, and relative abundance from year to year. Electrofishing in tributaries containing high densities of juvenile cutthroat is another recommended monitoring tool to indicate cutthroat numbers. Changes in tributary cutthroat populations could serve to indicate local habitat changes. Because tributaries produce juvenile cutthroat recruitment for the larger rivers and for Flathead Lake, changes in the abundance of cutthroat in tributaries could be expressed throughout the Flathead drainage.

Kokanee

The most abundant game fish in the Flathead drainage is the kokanee salmon *(Onchorynchus nerka),* a land-locked race of the Pacific sockeye salmon. Kokanee were introduced to Flathead Lake in 1916, and the population became established during the next two decades. Kokanee depend on the food resources of Flathead Lake and undertake annual migrations to reach suitable spawning habitat in the river system and along the lakeshore.

The 10- to 15-inch kokanee provide an extremely popular fishery for boaters in Flathead Lake through most of the year. During the fall, concentrations of spawning kokanee in the upper Flathead River system and along the Flathead Lake shoreline serve as a magnet for anglers and for a wide variety of wildlife, including bald eagles, otters, and bears.

Since 1977, however, the numbers of kokanee in Flathead Lake have declined. Part of this decline is linked to a reduction in the population of spawners using the mainstem Flathead River, formerly a key recruitment source of young kokanee for Flathead Lake.

Fishing at Flathead Lake Wayfarers Access Site, Bigfork

A second factor is the reduction in the number of spawners and in the production of young fish from the shoreline of Flathead Lake.

Since the late 1970s, biologists with the Montana Department of Fish, Wildlife and Parks have investigated the reasons for these population declines. This research has documented the life history of kokanee in the Flathead drainage. Although not all studies have been completed, the research has generated some specific flow recommendations in the Flathead River below the South Fork to enhance the kokanee population.

Life cycle overview. Fertilized kokanee eggs begin developing in the gravel redds after the fall spawning period. The embryos develop slowly through the winter, passing through an eyed staged before hatching as "sac fry", inch-long fish with yolk sac attached to their underside. The sac fry remain amidst the gravels for up to six weeks before emerging into the overlying water.

Fry generally emerge from mid-March through early June, with the site-specific timing dependent on local water temperatures and the date of spawning during the preceeding fall. Cold water temperatures and later spawning delay the date of fry emergence; warmer temperatures or early spawning advance development and contribute to early emergence. Many kokanee which hatch in a river or stream head downstream immediately after absorption of the yolk sac, while some fry may remain and feed in spring-influenced areas for several weeks. Studies have shown great variability in the rate of movement of kokanee fry downstream to Flathead Lake.

Most kokanee spend four or five growing seasons in Flathead Lake before reaching sexual maturity. Growth rates in the lake depend on population size. When populations are high, growth rates are relatively slow and mature fish average around 12 inches in length. Low populations lead to fast growth rates and mature fish averaging up to 15 inches.

The relationship of fish size to population results from the schooling and feeding behavior of kokanee. Fish hatched in the same year form large schools, and the fish feed as the schools move through the lake. The more fish in the school, the less food is available for each fish so growth rates are retarded. In years with few fish in each school, there is less competition for food and the fish grow larger.

The majority of migrating adult kokanee appear in the Flathead River in late August and move upstream at a rate of one to five or more miles per day. This early spawning run consists primarily of fish which move up the Middle Fork and into McDonald Creek in the southwestern corner of Glacier National Park. Most of these kokanee reach the McDonald Creek spawning area by the end of October. A second major run of spawning kokanee enters the Flathead River in early October. Most of these fish spawn in the mainstem river. Shoreline spawning in Flathead Lake peaks in mid-November. Adult salmon die after spawning, and the dead and dying salmon form an important seasonal food resource for many species of wildlife.

Spawning site distribution and relative abundance of spawners. McDonald Creek is presently the major spawning area for kokanee in the Flathead drainage. This Middle Fork tributary held 75% of all redds counted during autumn of 1981 and 1982, while the mainstem Flathead River ranked second with 13% of the redds. The Whitefish River, the lower Middle Fork, and several other Middle Fork tributaries held the remainder of river spawning sites. Despite extensive lakeshore surveys, Flathead Lake contributed only 4% of the kokanee redds in the Flathead system during the 1981-1982 period.

The survival of kokanee fry through incubation, through emigration to Flathead Lake, and during lake residence all influence the number of returning spawners. Because most kokanee spawning in the upper Flathead River system have a four year life cycle, the numbers of returning spawners in a given year can reflect the incubation and fry survival conditions four years previously. During 1981, the McDonald Creek spawning run was estimated at 84,000 to 111,000 fish. This run, the highest total during the past four seasons, probably reflects good incubation conditions in the creek during the winter of 1977-78, good survival conditions for fry emigration, and favorable conditions during the lake growth period. During the fall of 1982, only about 35,000 kokanee were estimated to have returned to spawn in McDonald Creek, reflecting poor survival in one or more stages of the life cycle of the 1982 year-class of kokanee. The extremely cold conditions and the extensive ice buildup in the spawning area during the winter of 1978-79 have been cited as a possible cause for the reduced 1982 McDonald Creek run.

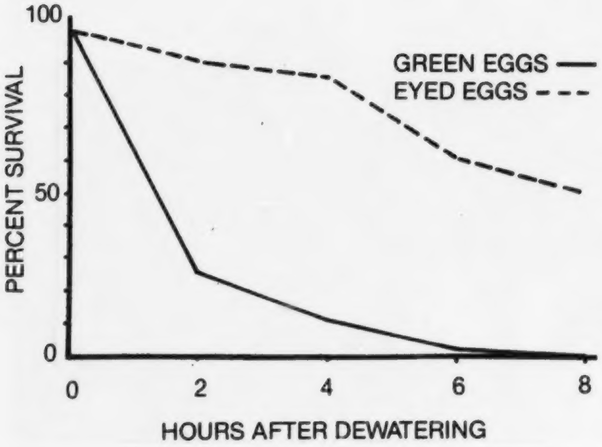
Sampling bottom substrate

From March through June, 1982, an estimated 12,000,000 kokanee fry emigrated from McDonald Creek on their way to Flathead Lake. This estimate, based on trap sampling of fry emerging from the spawning gravels, indicates a relatively good survival rate of 22% from egg deposition to fry emigration. Beaver Creek was also an important area for recruitment of kokanee, with an estimated 429,000 fry emigrating downstream from spawning areas in this Middle Fork tributary. Studies are now underway to determine what percentage of fry emerging from spawning sites are likely to reach Flathead Lake.

The effects of Hungry Horse Dam on Flathead River kokanee spawning. Populations of kokanee spawners in the mainstem Flathead River grew rapidly during the 1950s and remained high through the 1960s. During the last eight years there has been a population decline, with the mainstem spawning run dropping from an estimated several hundred thousand fish in 1975 to a four-year average of about 14,000 fish from 1979 through 1982.

FIGURE 5.28

Survival of Kokanee Eggs After Dewatering



Percent survival (average survival in four sediment mixtures) of kokanee eggs in the green and eyed stages during dewatering experiements in 1981-82. The green egg experiment was conducted on 5, 6 January (air temperatures -13 to -23°C) and the eyed egg experiment was conducted on 20, 21 January (air temperatures -13 to -18°C).

The rise and subsequent fall in the numbers of kokanee spawning in the Flathead River are largely related to the operation of Hungry Horse Dam. With the completion of the dam in 1953, the mainstem Flathead River below the South Fork began receiving discharges from the 250-foot depths of Hungry Horse Reservoir. The relatively warm reservoir waters raised winter temperatures in the Flathead River from normal near-freezing levels to almost 40°. Researchers hypothesized that the warmer water temperatures, coupled with high flow releases from the dam, reduced ice formation on the gravel-bottom runs near the river banks, the preferred spawning areas for kokanee. The result was improved survival of kokanee eggs in the river and a rapid buildup of Flathead River spawning populations during the 1950s and 1960s.

During the late 1960s, Hungry Horse Dam changed its seasonal operation pattern and began generating peak power during the fall months. High flows during the spawning season allowed kokanee to deposit their eggs at sites which were later dewatered by low flow releases during the winter incubation period. Kokanee eggs in these sites were subject to freezing and drying, and relatively few eggs survived the incubation period (Fig. 5.28). During 1979-80, for example, dewatering resulted in nearly complete mortality of the eggs in mainstem Flathead redds located above the low-water mark.

Redds located in sites influenced by springs and spring-fed sloughs remained underwater or wetted, independent of fluctuations in the level of the Flathead River.

The impact of the peak power regime on the Flathead River spawning run has been dramatic. Researchers estimated several hundred thousand kokanee returned to spawn in the mainstem Flathead River in 1975; during 1981, the run was down to 35,000 and the 1982 run was estimated at only 5,000 fish. Sharply reduced harvest of mainstem-spawning kokanee by anglers has accompanied the decline in the run of river spawners, and most fishermen (snaggers) have shifted their attention to the early run of spawners destined for McDonald Creek.

The size of kokanee which return to spawn in the mainstem Flathead River each year is affected by survival during incubation four years earlier. Flow conditions suitable for successful incubation result in good recruitment of young fish to Flathead Lake. Growth rates in Flathead Lake for fish in such a high-population year-class are slower, and spawners returning four years later will be shorter. Conversely, poor incubation conditions in the river lead to low populations in a given year-class and larger individual spawners four years later. The numbers of kokanee recruited into Flathead Lake from other spawning areas, such as McDonald Creek and the lakeshore, also affect population size, individual growth rates, and the size of returning spawners for each year-class.

Kokanee size extremes documented in the Flathead River during the last 30 years occurred in 1967, when spawners averaged just under 11 inches, and in 1982, when spawners averaged 15 inches. The consistency of the relationship of incubation flow conditions to the size of returning spawners has been well documented by fisheries researchers.

In 1981, the Montana Department of Fish, Wildlife and Parks recommended a pattern of flow releases from Hungry Horse Dam designed to increase the mainstem spawning run of kokanee to 1975 levels. These recommendations, formally adopted by the Pacific Northwest Electric Power and Conservation Planning Council in 1982, require the Bureau of Reclamation to adjust flow releases into the Flathead River to insure that (1) adequate spawning sites are avilable during the fall, (2) redds will not be dewatered during the winter incubation period, and (3) emerging fry will experience high enough flows to be carried downstream to Flathead Lake.

Biologists targeted the 1975 river-spawning kokanee population because this run is believed to provide an optimal balance between kokanee size (13-inch average) and numbers (several hundred thousand river spawners). Although higher populations might be produced by varying the flow regime, the result would be a smaller average fish size and presumably lower satisfaction for anglers fishing in both the lake and the river.

Implementation of the flow releases began in the fall of 1982. Because of the severely depressed number of spawners, complete recovery of the Flathead River population is expected to take about 12-16 years (three or four generations). The low spawning runs of 1980 and 1982 will likely result in smaller even-year spawning populations (1984, 1986, etc.) than in odd years because kokanee are generally on a four-year population cycle.

Impacts of water regulation on kokanee reproduction in Flathead Lake. During the 1930s and 1940s, Flathead Lake accounted for a major proportion of the kokanee spawning in the Flathead drainage. In 1933, a Polson cannery processed 21,000 cans of kokanee from fish netted from shoreline spawning beds, as part of a program to provide food for the needy. High spawning concentrations were observed along the lakeshore during the early 1950s.

The number of lakeshore spawning sites used and the numbers of spawning kokanee are much lower today than during the 1950s. In 1981, the Montana Department of Fish, Wildlife and Parks began an intensive research program to document kokanee spawning along the Flathead Lake shoreline and to determine the effects of water regulation by Kerr Dam and Hungry Horse Dam on shoreline spawning. The research, sponsored by the Bonneville Power Administration, will continue through 1987.

During autumn 1981 and 1982, kokanee redds were located within nine bays on the east shore of Flathead Lake and in Crescent Bay on the west shore. All shoreline spawning areas were influenced by a surface stream or groundwater seep, indicating the importance of water flow in providing oxygen and removing metabolic wastes from the developing eggs.

Over 1,000 shoreline redds were counted during 1982 and 592 were recorded during 1981. The largest concentration of spawning kokanee occurred at Yellow Bay in 1981 and in Gravel Bay in 1982. Other important spawning areas included Woods Bay and seven separate shoreline locations in the southeast sector of the lake, from Blue Bay south to Skidoo Bay.

Reduced incubation survival, and thus reduced kokanee populations, have been related to water level fluctuations in many reservoirs in the western United States. Kokanee spawned along the shorelines during

West Shore of Flathead Lake

high lake levels, but subsequent reservoir drawdowns dewatered the spawning areas and exposed the eggs to freezing and drying during the incubation period. These findings from other reservoirs indicate that the operation of Kerr Dam may be playing a part in the decline of lakeshore spawners in Flathead Lake. During 1981 and 1982, 55% of the kokanee redds surveyed on the Flathead Lake shoreline were located above the level of minimum drawdown.

Researchers are continuing to gather information on the relation of water level fluctuations in Flathead Lake to kokanee spawning success along the shoreline. The influence of groundwater on the incubation of kokanee eggs, and the influence of shoreline development on groundwater quality, are also being assessed through field studies. Additionally, researchers are reviewing the historical operation of both Kerr Dam and Hungry Horse Dam to gain insight on how water level management has affected shoreline habitat during recent decades.

Food habits. Kokanee in Flathead Lake feed steadily on crustacean zooplankton through the daylight hours. Prey capture is triggered by sight, and the kokanee demonstrate a high degree of selectivity for the larger zooplankters. The natural population cycles of each zooplankton species result in significant seasonal variations in the kokanee diet.

Daphnia thorata, the water flea, constitutes the most important item, particularly during the warm season. From June through November, *D. thorata* made up 72% of kokanee food by weight, based on studies conducted during 1980 and 1981. All age classes of kokanee feed selectively on the larger individuals of *Daphnia* (longer than one-twentieth of an inch).

The two largest crustaceans, *Epischura nevadensis* and *Leptodora kindtii,* are much more common in the kokanee diet than in the zooplankton population as a whole. During early summer, the one-tenth inch *Epischura* comprised from 30-60% of the food eaten by kokanee. This zooplankter became less important in the diet of kokanee as the larger *Leptodora* increased in abundance during mid-summer. Although about 2,000 times less abundant than *Daphnia, Leptodora* commonly made up 20-50% of the food of three-year-old and older kokanee in July and August. Individual *Leptodora* weigh three times as much as *Daphnia* and twice as much as *Epischura*. The importance of *Leptodora* in the diet, in spite of its relative scarcity in the zooplankton community, further indicates the kokanee selectivity for large zooplankton prey. By late autumn, *Leptodora* declines in abundance, and *Epischura* replaces it as the diet component second in importance to *Daphnia*.

T. Weaver and B. Shepard preparing to pull gill nets from Flathead Lake

Daphnia populations decline sharply in winter, and constitute less than 1% of the zooplankton population during January. *Daphnia,* however, remains the most available large zooplankter and continues to constitute up to 90% of the diet of individual kokanee. From mid-January through March, *Daphnia* is in a resting-egg stage and is thus absent from the zooplankton community. *Diaptomus ashlandi* replaces *Daphnia* in the kokanee diet through the later winter. The majority of *Diaptomus* found in kokanee stomachs were mature females bearing egg sacs, a condition which may increase the nutritive value of this zooplankter.

Daphnia appeared in the kokanee diet in mid-April, paralleling its re-establishment in the lake zooplankton community. Midge pupae constitute up to 7% of the kokanee diet in April when large numbers of these aquatic insects are emerging near shoreline areas.

Monitoring kokanee status. Kokanee populations in the Flathead system have fluctuated widely in response to the operation of Hungry Horse Dam on the South Fork. The implementation of new flow regimes from the dam will require evaluation of spawner numbers and harvest to see if the projected population recovery is occurring or if flow adjustments need to be made. This evaluation, mandated by the Northwest

Power Planning Council, is being carried out by the Montana Department of Fish, Wildlife and Parks with funds provided by the Bonneville Power Administration.

Study of the effect of water level fluctuations in Flathead Lake on shoreline spawning will proceed through 1987. Researchers with the Department of Fish, Wildlife and Parks will continue to investigate the habitat conditions necessary for successful shoreline spawning and the relative contribution of major shoreline areas to the kokanee population. Management and monitoring recommendations to aid the recovery of shoreline spawning populations will be issued at the study completion.

The dependence of kokanee on zooplankton populations in Flathead Lake mandates careful monitoring of the abundance and species composition of the zooplankton community. Any environmental changes which affect the water quality or productivity of Flathead Lake for algae will likely be expressed in changes in the populations of zooplankters which depend on algae for food. The concern over changes in lake productivity is particularly important in light of the evidence generated through the Flathead River Basin Environmental Impact Study that nutrient additions from domestic sewage are increasing the productivity of algae in Flathead Lake. The discovery of *Mysis* shrimp in Flathead Lake and the possibility of future establishment of this large zooplankter also have the potential to alter the zooplankton community. Researchers have recommended a monitoring program consisting of once-a-month zooplankton sampling during the cool season and twice-a-month sampling during the warm season to assess the status of the kokanee food base. Evaluations of other lakes containing *Mysis* are also planned to assess the potential impacts of *Mysis* establishment on kokanee in Flathead Lake.

Creel Census Results

The fishery resource of the Flathead drainage is of tremendous recreational and economic importance. Maintaining this resource depends not only on the conservation of the high quality aquatic ecosystem, but also on the management of fish harvest.

During the early 1980s, the Montana Department of Fish, Wildlife and Parks conducted extensive surveys of angler use and fish harvest to assess characteristics of fisherman use and fish harvest on Flathead Lake and the upper Flathead River system. Information on harvest levels and catch rates provides a baseline against which future conditions can be compared to monitor the status of the fishery and to indicate appropriate management actions. Some highlights of creel census work, sponsored by the Flathead River Basin Environmental Impact Study and the Bureau of Reclamation, are presented here.

Flathead Lake Fishery

Fish harvest and angling pressure on Flathead Lake were documented through a year-long census which concluded in May 1982. Fishermen caught over half a million game fish, with kokanee comprising 92% of the catch (Table 5.16). The annual average catch rate for kokanee was one fish per hour, the highest success for any game fish in the lake. Kokanee fishermen experienced their highest catch rates during February and March when a locally intense fishery developed for concentrated kokanee schools in one bay in the southeast portion of Flathead Lake.

The majority of bull trout were caught at the north end of the lake, in spring, when bull trout concentrated just prior to entering the Flathead River for their upstream spawning migration, and in fall, when bull trout spawners were returning to the lake from the Flathead River. Slightly more than half of the bull trout caught in Flathead Lake were released, primarily as a result of the 18-inch minimum size limit. This limit is intended to conserve stocks of juvenile fish, and thus insure adequate recruitment into the population of adult spawners.

Lake trout, or mackinaw, harvested from Flathead Lake averaged 31 inches in length, and fish over 20 pounds were frequently caught. In general, lake trout fishing was a deep-water sport, with wire line or downriggers used to fish at depths of 100 feet or more. The combined catch rate of bull and lake trout by boat anglers fishing specifically for these two species was about one fish for six hours of fishing.

An average of only one in twenty anglers caught a cutthroat trout in Flathead Lake, and most catches by boat anglers were incidental to pursuit of kokanee or bull trout. Occasionally, good catches of cutthroat were reported by shore anglers.

Two distinct and highly localized fisheries for yellow perch exist in Polson Bay. About half of the perch were taken by ice fishermen during winter, while the other half of the perch harvest occurred from May through July and was equally divided between boat and shore fishermen.

TABLE 5.16

Total estimated monthly harvest of six major fish species from Flathead Lake for the period May 16, 1981 through May 14, 1982.

	Number of fish						
Month	**Kokanee**	**Bull trout**	**Lake trout**	**Cutthroat trout**	**Yellow perch**	**Whitefish**	**Total**
Jan	4,787	233	233	28	9,363	166	14,800
Feb	29,874	222	598	0	578	97	31,369
Mar	83,435	255	408	170	0	0	84,268
Apr	17,168	348	177	367	0	45	18,105
May	5,320	687	509	986	4,989	145	12,636
Jun	46,353	508	659	900	732	125	49,277
Jul	106,620	549	843	1,398	3,833	37	113,280
Aug	136,588	443	842	1,020	0	0	138,893
Sep	42,615	277	216	431	0	0	43,539
Oct	18,775	1,061	265	392	0	133	20,626
Nov	3,342	289	325	36	0	0	3,992
Dec	1,033	580	1,882	1,182	1,408	0	6,085
TOTAL	495,910	5,452	6,947	6,910	20,903	748	536,870
% harvest	92.4	1.0	1.3	1.8	3.9	0.1	
Ave. size (in.)	12.3	22.6	31.3	12.6	—	—	

Angling pressure shifted seasonally, with most boats pursuing bull trout and lake trout during late fall and winter and kokanee during the warmer months (Fig. 5.29). Exceptions to this pattern occurred in late spring, when anglers sought bull trout near the mouth of the Flathead River, and during February and March, when anglers took advantage of a local kokanee concentration in the southeast portion of the lake.

Anglers expended an estimated 600,000 hours fishing on Flathead Lake during the year-long census period. Over 90% of the fishing was conducted from boats. Sixty-one percent of the anglers surveyed were from Lake and Flathead counties, 21% were from other Montana locations, and 18% were nonresidents of Montana. Only 1% of the anglers surveyed on Flathead Lake were from Canada.

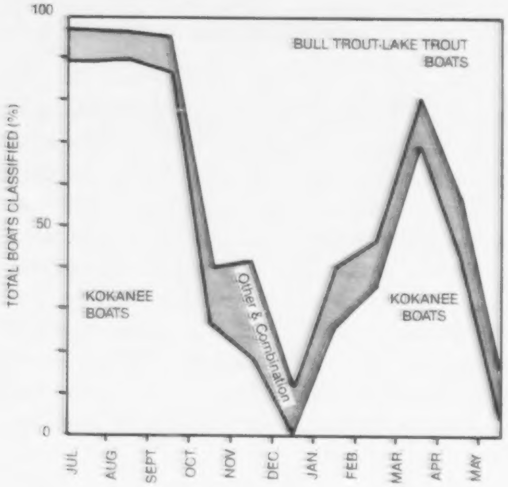
Flathead River System Fishery

The fishery on the mainstem Flathead River reflects seasonal migrations of the major game fish and is characterized by two periods of peak use. During early summer, anglers concentrated on spawning migrations of bull trout and cutthroat trout, while during fall most fishing pressure was directed at the spawning run of kokanee salmon.

The highest numbers of bull trout were caught in May and June in the mainstem Flathead River. Bull trout were taken on both bait and lures, with the majority of the harvest being recorded by shore anglers. As in Flathead Lake, slightly over half of the bull trout caught were released because they did not attain the minimum 18-inch legal size. The bull trout catch in the mainstem river was dominated by juveniles during August, when most adult fish had moved upstream to the forks of the Flathead on their way to spawning tributaries. Many returning bull trout spawners were caught during November in the section of the Flathead River just above Flathead Lake. An estimated 1,800 adult bull trout were harvested in the mainstem Flathead River during 1981.

FIGURE 5.29

Boat Fishing throughout the Year in Flathead Lake



Monthly distribution of boat types for 1,399 boats classified by species of fish pursued on Flathead Lake from July 1, 1981, through May 14, 1982.

Cutthroat harvest peaked in July and August on the mainstem Flathead River. This catch was dominated by 8-inch juvenile fish migrating downstream from the tributaries on their way to Flathead Lake. Most adult cutthroat were caught during early summer or late fall. The adult fish generally ranged in size from 14 to 16 inches, and occasionally reached lengths of 18 inches. About 9,000 cutthroat of all sizes were harvested from the mainstem Flathead River.

Total angler harvest on the North Fork in Montana was estimated at 18,000 fish, of which 91% were cutthroat, 6% whitefish, and 2% bull trout. The North Fork provided primarily a summer fishery, with juvenile cutthroat on their downstream migration comprising the bulk of the harvest. The majority of the harvest of migrating adult bull trout on the North Fork occurred in July.

Kokanee harvest in the Flathead River system varies widely between years, reflecting the varying numbers of returning spawners. In 1975 and 1981, anglers snagged an estimated 150,000 kokanee during the fall spawning runs up the mainstem Flathead River and the Middle Fork; in 1982, the harvest was only about one-tenth this level, reflecting the extremely low number of kokanee returning to spawn in the mainstem Flathead River.

The timing and location of the kokanee harvest in the river system also shifts from year to year. The high harvest levels in 1975 were primarily recorded in the mainstem river during October. The majority of these kokanee spawners were headed for spawning areas in the mainstem Flathead River. During 1981, most of the kokanee harvest in the Flathead River occurred during September, representing angler use of the early run of kokanee headed for spawning grounds largely in McDonald Creek in the Middle Fork drainage. About half of this 1981 harvest was taken from the Middle Fork, while the other half was taken as the spawning run moved through the mainstem Flathead River.

Over 90% of the kokanee harvest was by snag fishermen. Snagging represents the most productive way to catch kokanee during the fall because these fish do not generally feed during the spawning run. During the early part of the spawning run, however, many kokanee are taken on lures.

LAND-WATER INTERFACE

The integrity of the Flathead aquatic system depends on the management of surrounding lands. Many land disturbances, such as timber harvest, agriculture, mining, and residential development, have a potential to cause the release of sediments and nutrients which can alter physical, chemical, and biological processes within Flathead waters. Fish populations and water quality, two of the most valued features of the Flathead aquatic ecosystem, are among the components most sensitive to sedimentation and nutrient pollution.

Although the Flathead system is now relatively pristine, the Flathead River Basin Environmental Impact Study has documented a trend of declining water quality. Continued growth of the regional population and increasing natural resource development activities promise further changes in the aquatic environment. This subchapter reviews the effects of land-use activities on the aquatic resources of the Flathead Basin, based on the understanding of river ecology, lake ecology, and fisheries gained through the Flathead Basin study. The discussion of the land-water interface focuses on the influences of man-caused sediment and nutrient additions on stream habitat and lake productivity.

The land-water interface also encompasses the streamside or riparian zone, a productive terrestrial habitat that depends on river processes for its continued existence. Like the aquatic system, the riparian zone is an important but vulnerable component of the Flathead ecosystem. Wintering concentraitons of big game mammals and summer populations of breeding birds depend on the narrow riparian corridor along the Flathead River and its forks; riparian vegetation also plays an important role in maintaining the integrity of the stream environment. The level flood plains and adjacent terraces, however, are readily accessible to man and have historically served for agriculture, urban development, resource extraction, and transportation routes.

An understanding of how the land and water systems interact will allow changes observed through monitoring of the aquatic system to be related to land-uses within the basin. Resource specialists can then suggest management options to prevent activities on the land from jeopardizing the values of the water. In this manner, informed Flathead Basin citizens will have the opportunity to work with local, state, federal, and international policy makers to insure the long-term conservation and wise use of the aquatic system.

Nutrients

A natural shortage of biologically available phosphorus limits algal growth in the Flathead aquatic system and thus helps maintain good water quality. In recent years, however, man-caused (cultural) additions of phosphorus have significantly increased the productivity of Flathead Lake for algae, thus initiating the process of cultural eutrophication. The lake is now classified as oligo-mesotrophic, a borderline status which indicates that additional phosphorus loading would cause noticeable deterioration in water clarity and undesirable shifts in plant and animal communities.

Dissolved nitrogen-containing compounds, usually in the form of nitrates, also enter Flathead waters as a result of human activities. Nitrates are also an important plant growth nutrient. Nitrates have contaminated groundwater supplies in some sites within the Flathead Basin, and this nitrate pollution indicates some of the problems inherent in the disposal of wastewater into the aquatic system.

Community sewage treatment facilities, and on-site septic systems contribute both nitrogen and phosphorus to the aquatic system; sedimentation due to land-use activities is another important cultural source of phosphorus.

Community Sewage

A significant identified cultural source of nutrients from the land environment to the aquatic system is domestic sewage processed through community sewage treatment plants. Sewage loads tracked the rapid regional population growth during the 1970s, and community sewage systems now contribute an estimated 17% of the total load of biologically available phosphorus in the lake. According to simulation models of the lake environment, this phosphorus contribution from sewage, has probably increased algae productivity by at least 10% over baseline levels.

Nitrates from sewage adds an estimated 79.1 tons of nitrogen annually to the aquatic system, or about 5% of the Flathead Lake nitrogen load. Although nitrogen is generally more available than phosphorus in the

Main street, Kalispell

lake, during some times of the year essentially all usable nitrogen is incorporated into plant or animal tissues. Additions of nitrogen under these conditions can directly stimulate primary productivity. Cultural nitrate loading may also act to change the species composition of algae in Flathead Lake, which could in turn affect zooplankton and fish. Further research is needed to ascertain the dynamics of nitrate movement in the lake ecosystem and the impact of cultural additions of nitrates to Flathead Lake.

Municipal sewage treatment plants in Kalispell, Whitefish, Columbia Falls, and Bigfork collect wastewater from the major populated centers upstream from Flathead Lake. Each of these facilities utilizes secondary treatment, a process which removes solid materials and reduces bacterial numbers. Secondary treatment, however, removes only a small percentage of the phosphorus and nitrogen compounds in sewage, primarily through the process of sludge (solid waste) removal. As a result, discharges from these sewage treatment facilities retain the high dissolved nutrient concentrations characteristic of raw sewage.

As population growth continues in the Flathead Basin, ever-increasing amounts of phosphorus and nitrogen will be discharged into the aquatic system by the municipal sewage treatment plants. Without corrective action, Flathead Lake will continue to grow more productive of algae and less desirable for a range of recreational activities.

Advanced, or tertiary, sewage tretment removes nutrients from wastewater and thus offers an effective method of reducing the phosphorus loading of Flathead Lake. The phosphorus is generally removed through chemical precipitation or through the application of secondarily treated wastewater to the soil, which retains phosphorus by adsorption. Nitrogen is removed by bacterial action or by land application and subsequent uptake by plants. Efficiently operating tertiary facilities can remove 90% or more of dissolved phosphorus and up to 80% of dissolved nitrogen from sewage. The sewage treatment plant at the University of Montana Biological Station at Yellow Bay on Flathead Lake is currently the only tertiary facility in the Flathead Basin. A proposed housing development above the Flathead Lake shoreline west of Bigfork has received approval for a sewage treatment facility which will remove phosphorus.

Conversion of the existing secondary sewage treatment plants to tertiary treatment promises to become an important fiscal and public policy issue for communities in the Flathead River drainage. Upgrading to a phosphorus-removal system is under consideration in Bigfork, where residents and officials are planning to improve the existing sewage treatment plant to improve its efficiency and to accommodate expected residential growth. Tertiary processing would probably be more expensive than simply renovating the secondary plant, but some residents believe the larger immediate costs will be balanced by the long-term benefits of maintaining lake water quality.

Kalispell just completed design of a $2.6 million improvement in the solid waste handling facility at its municipal sewage treatment plant on Ashley Creek. Additional upgrading of the facility is necessary to limit discharges of ammonia, and design modifications to correct the ammonia problem could incorporate removal of phosphorus. A phosphorus removal facility as part of the Kalispell sewage treatment plant would

View of Bigfork across Flathead Lake

address the largest single source of phosphorus to the Flathead aquatic system; this plant alone now accounts for approximately 10% of the annual phosphorus loading of Flathead Lake.

During 1981, Whitefish completed a $2 million project to upgrade its existing secondary treatment plant, and Columbia Falls is in the midst of a $2 million renovation of its secondary plant. These improvements will bring the facilities into compliance with current state water quality standards for wastewater discharge, but neither facility is designed to remove phosphorus. Operational modifications of the Whitefish plant could allow for some phosphorus removal, while the Columbia Falls plant would likely require substantial and costly alterations to incorporate phosphorus or nitrogen removal.

The Water Quality Bureau of the Montana Department of Health and Environmental Sciences monitors the operation of sewage treatment facilities and sets discharge standards based on local and regional water quality objectives. Sewage treatment plants typically have a physical life expectancy of about 20 years, but may have to be renovated earlier to accommodate population growth or to meet discharge standards. Nutrient removal could be required as a condition of the wastewater discharge permit if state officials believe this step is necessary to conserve water quality values.

Through 1984, the U.S. Environmental Protection Agency may pay 75% of the costs of improving sewage treatment facilities to meet state and federal water quality standards. The federal share of this construction grant program drops to 55% as of October 1, 1984; however, communities utilizing advanced treatment methods, including nutrient removal systems, may still be eligible for the 75% level of federal funding if the need for advanced treament can be justified. Federal grants for sewage treatment facilities are uncertain after October, 1986, when the authorization for the current cost-sharing programs runs out. Both Kalispell and Bigfork could probably take advantage of the currently available federal money to institute phosphorus removal treatments, when these communities take required steps to improve their existing facilities. Federal construction grants were used by Kalispell, Whitefish, and Columbia Falls to fund part of their recent improvements in wastewater treatment.

Regulation of detergents is another alternative to help reduce the phosphorus loading of the Flathead aquatic system. A decade ago, laundry detergents were estimated to contribute 50-70% of the phosphorus in domestic sewage. Many detergents have reduced their phosphorus content, but detergents remain an important phosphorus source. Phosphate detergents have been banned in many communities across the United States because of their role as nutrient contributors to freshwater lakes, and nonphosphate soaps are available. Attempts to restrict the use of phosphate-containing detergents in Montana have failed in several recent sessions of the Montana legislature. No local or regional ordinances have yet been adopted to address the problem of phosphorus pollution from detergents in the Flathead drainage. The adoption of such ordinances would offer a measure of protection to the water quality and biological communities of Flathead Lake; however, if the anticipated population growth and attendant increased sewage discharges occur, regulation of detergents would probably provide only a temporary improvement in regional phosphorus loading.

Septic Systems

On-site residential sewage disposal systems are another cultural source of nutrients to the aquatic system. The number of septic systems in Flathead and Lake counties increased by 48% during the 1970s as a result of the rapid increase in rural housing developments; an estimated 60% of the homes in the two-county region now rely on septic systems for sewage disposal.

A septic system collects solid wastes in a large holding tank and channels wastewater through the drainfield, an underground series of perforated pipes. The wastewater then flows slowly out of the drainfield and percolates into the soil. In a septic system that is properly located and constructed, septic effluent passes

B. Baumen preparing to measure permeability of Flathead soils through at least four feet of soil before reaching the groundwater. During this slow drainage, most contaminants are filtered, broken down chemically, or adsorbed on the surface of soil particles, thus purifying the water which eventually enters the groundwater.

The character of the soil is the single most important factor in determining the success of an on-site waste disposal system. If the soil is relatively impermeable and the septic drainage field is small, water may be unable to flow from the drainage pipe as fast as water is being discharged from the household. The result is hydraulic failure, evidenced by backed up drains and overflowing toilets. Hydraulic failures also can occur when spring runoff or summer irrigation raise the water table enough to submerge the drainfield and thus prevent sewage outflow.

Treatment failure, on the other hand, results if soil characteristics or a high water table allow rapid entry of wastewater into the groundwater. In this case, the effluent moves through the soil too quickly for the soil particles to remove phosphorus, bacteria, or other impurities. Treatment failures often go unnoticed by homeowners because drainage from the house remains good and the septic system thus appears to be functioning properly.

Soil particles have a tremendous capacity to adsorb and hold phosphorus, and discharge of phosphorus into the groundwater is rarely a problem in properly constructed drainfields. Glacial till deposits, characteristic of most valley areas in the Flathead Basin, generally have a high percentage of fine sediments and thus provide very good phosphorus retention. Sandy, gravelly, or cobbly soils, formed by alluvial (moving-water) deposition, have relatively few adsorption sites for phosphorus. These soils have the potential to allow sewage phosphorus to move into ground and surface waters. River flood plains and adjacent terraces, along with certain lakeshore sites, are critical areas for future development because of the potential for wastewater treatment failure, and septic systems constructed in these areas require careful design and location. Discharge of phosphorus from septic systems into groundwater can also occur when seasonal high water reduces or eliminates the space between the septic drainpipe and the water table.

Most nitrogen compounds are neither filtered nor adsorbed by the soil. A series of oxidative chemical reactions in the septic tank and in the soil converts the nitrogen compounds in sewage into nitrates, which remain dissolved in the wastewater as it percolates through the drainfield. In areas with a high density of septic systems, nitrates from sewage effluent can reach high enough concentrations to contaminate the groundwater. Nitrates in the groundwater may subsequently pollute domestic wells or add undesirable nutrients to surface waters if the groundwater emerges into streams or lakes.

A recently completed remote-sensing study, which correlated high-altitude multi-spectral scanning data with lake water quality sampling, indicated that high concentrations of nitrates are being discharged into the Flathead River from the residential Evergreen area north of Kalispell. Evergreen, located on the Flathead River flood plain and adjacent terraces, is not served by a community sewer and waste disposal system; individual septic systems thus constitute the only method of domestic wastewater treatment and disposal in this area. Apparently the high density of septic systems in Evergreen is loading the underlying flood plain aquifer with nitrates, and the natural southward flow of this groundwater is carrying the nitrates into the Flathead River.

Phosphorus from septic systems has apparently entered the Evergreen groundwater, as evidenced by high levels of phosphorus found in test wells drilled in the flood plain aquifer. Although most septic drainfields retain phosphorus, conditions in the low-lying Evergreen area are not always conducive to proper wastewater treatment. During spring runoff, the high floodplain water table may bring groundwater in contact with phosphorus-laden drainfield soils and release phosphorus into the aquifer and subsequently to Flathead River. The relatively coarse flood plain soils in some sites also have a limited capacity to adsorb phosphorus, which may also contribute to phosphorus discharge into the Flathead River. If further groundwater studies indicate that significant amounts of phosphorus are being flushed into the Flathead River through groundwater flow beneath Evergreen, construction of a sewage collection and treatment system for Evergreen may become an important regional consideration for the conservation of water quality in Flathead Lake.

Nitrates from septic wastes have contaminated domestic groundwater supplies northwest of Flathead Lake, where residents' complaints about bad tasting water led to extensive groundwater sampling during 1982. Although harmful nitrate concentrations were found in only a few wells, the contamination extended over a distance of more than 10 miles from the lakeshore to Lone Pine State Park west of Kalispell. Groundwater in this region exists in fractures in the limestone bedrock, and hydrologists believe that nitrates from septic systems are being channeled over long distances through the limestone fractures. Direct sewage pollution of Flathead Lake is occurring at the Mission View Terrace housing development near Lakeside. In this subdivision, a concentration of residential septic systems lies in the path of the natural groundwater flow from the limestone aquifer to the lake. The groundwater saturates the drainfield soils, and carries sewage effluent, including nitrogen, phosphorus, and bacteria, into the lake, without the benefit of adequate treatment by soil.

The Mission View Terrace development has received considerable attention as the focus of the detailed hydrologic studies conducted by the Flathead Drainage 208 Project. Researchers caution, however, that this subdivision should not be viewed as a unique case. Seven separate seepages from the limestone aquifer into Flathead Lake have been located along the shoreline between Lakeside and Somers, and each has the potential for discharging sewage effluent into the lake. Additionally, septic drainfields in other lakeshore sites are set in gravels, and thus may be locally important sources of phosphorus and other contaminants to Flathead Lake.

The potential for cultural eutrophication of Flathead Lake is greatest in isolated bays, where phosphorus from shoreline developments can circulate in restricted bay areas without being diluted by the main lake currents. Increased algal productivity has been documented in Flathead Lake bays and is believed to be caused by shoreline phosphorus pollution.

The bottom of Somers Bay hosts zinc concentrations three to five times the average concentration in other Flathead Lake sediments. These high zinc levels have apparently resulted from groundwater movement, which has flushed sewage effluent (a common zinc source) and industrial wastes from beneath Somers into Flathead Lake. Additional study is needed to ascertain the potential for groundwater flows to carry pollutants, including phosphorus, from lakeshore communities into the lake.

Construction of sewer lines and advanced treatment plants is one method to alleviate potential nutrient pollution from residential developments along the Flathead Lake shoreline; however, premature construction of community facilities could have serious negative environmental implications. Centralized sewage facilities increase the suitability of land for high density development and the high costs of construction can force landowners to generate more revenue from the land base. These pressures can result in shifts from agricultural uses or low density developments to condominiums or high density subdivisions. Centralized sewage facilities with nutrient removal can also be difficult to maintain properly, because the seasonal nature of recreational use leads to large fluctuations in sewage discharges.

Looking west from Somers across Somers Bay, Flathead Lake

High monetary costs, potential adverse environmental effects, and operational difficulties underscore the importance of careful review and planning before reaching decisions on whether to develop centralized wastewater collection and treatment facilities. Where population densities warrant, local sewage and waste disposal facilities would minimize the lakeshore contributions of phosphorus. The Somers-Lakeside area and the residential area northwest of Polson have been identified as locations where high population densities and problems with on-site sewage treatment may make construction of centralized sewage and waste disposal facilities desirable. Meanwhile, most areas around the lake will continue to rely upon on-site sewage and waste disposal systems. Presently only Polson, Bigfork, and the University of Montana Biological Station at Yellow Bay have community sewage treatment systems, and only the Biological Station treatment plant is designed to remove phosphorus.

Research sponsored by the Flathead River Basin Environmental Impact Study quantified the drainage capacity (permeability) of various Flathead Basin soils under a range of moisture conditions. Because of the extreme local variability of soil characteristics, soil scientists concluded that a site-specific assessment of soils is necessary to locate and design a septic drainage field that will provide both adequate drainage and adequate treatment of the wastewater effluent. Information on soil characteristics and the guidelines for drainfields developed through this research should help insure that new septic systems in the Flathead Basin will reduce the amount of phosphorus and organic wastes entering the aquatic system.

Much remains to be learned about the dynamics of phosphorus discharge from septic systems into groundwater and surface waters in the Flathead drainage. Developments in critical areas along the Flathead River floodplain and the Flathead Lake shoreline are apparently contributing phosphorus to the aquatic system, but quantitative measurements are needed to establish the amount of phosphorus loading attributable to on-site wastewater disposal systems. This information will allow future decisions on the construction of community sewage facilities to be based on considerations of lake productivity, as well as traditional water quality concerns.

Nutrient Contribution of Sediments

Natural erosion of fine phosphorus-containing sediments provides a significant nutrient input to the Flathead river and lake system. The rivers of the Flathead drainage flow through "young" geologic formations, with unconsolidated glacial tills overlying fine tertiary materials deposited prior to the ice ages. Sections of the North and Middle forks and their larger tributaries have downcut their channels into the tertiary deposits, and fine tertiary sediments are now exposed in highly erosive banks, sometimes reaching one hundred or more feet high. When spring runoff flows undercut these banks, sheets of silt- and clay-sized particles drop into the river channels. The fine sediments remain suspended in the current and are carried to Flathead Lake as the spring sediment plume. This predictable pulse of sediments and associated phosphorus has recurred annually during the 10,000-year existence of Flathead Lake and has helped shape the lake's biological communities.

The extractable phosphorus content of the sediments indicates their relative effect in fertilizing the growth of algae in Flathead Lake. Tertiary sediments analyzed at the University of Montana Biological Station had extractable phosphorus concentrations (Table 5.17) ranging from 10 to 26 parts per million (ppm), while chemical assays recently conducted by the Forest Service indicate that argillite, quartzite, and limestone tills contain only 0.2 to 1.4 ppm extractable phosphorus. These glacial tills comprise over 90% of

TABLE 5.17

Phosphorus concentrations (ugP/gm sediment) for selected erodable sediments within the Flathead River drainage.

Sediment Collection Sites	Organic	Inorganic	NaOH Extractable	NTA Extractable
North Fork at Kintla Creek	78	1640		
Flathead River south of Holt Bridge	90	386		
North Fork north of Tepee Creek	BDL	251	12	110
North Fork at Kintla Creek	25	577	26	393
North Fork at Ford Creek	384	172	10	51
Agassiz Creek at Upper Kintla Lake	96	437	24	39
Middle Fork north of Station 2	24	492	12	38

BDL = below detection limits

the Flathead drainage; the Tertiary banks which serve as the primary sources of sediment-associated phosphorus are highly localized along the major rivers.

Timber management, agricultural practices, and urban storm runoff also contribute phosphorus-containing sediment to the aquatic system, but quantifying these impacts is extremely difficult. Forest roads generate most of the sediments released by logging operations, channeling water flow through exposed mineral soil on the road surface and along the associated drainage ways. Sediment production from roads remains high as long as the road surface is unvegetated. Most sites, including clearcuts, typically revegetate with forbs, shrubs, or young trees in a few years, and the amount of surface erosion of sediments from cutover lands drops off sharply once plant cover is reestablished.

Logging also can have an indirect influence on sediment production through alteration of stream flow patterns. Land cleared of trees collects more snow than land with an intact forest canopy and once begun, snowmelt occurs very rapidly from open sites. This increased and temporarlly concentrated runoff may cause higher peak flows in the river system and greater erosion of the banks. Further research is needed to quantify the impacts of timber harvest on water yield and sediment production from forested watersheds in the Flathead drainage before specific conclusions or recommendations can be drawn.

The contribution of agriculture to phosphorus loading of Flathead Lake is largely due to sediment erosion. Irrigation return flows can saturate the soils and make banks susceptible to sloughing into the stream channel, a phenomenon which has caused recent problems along the Stillwater River. The bank sediments are natural phosphorus sources, and during high flows much of the fine sediments accumulated on the river bottoms are resuspended and carried into Flathead Lake. Agricultural fertilizers are also a potential source of phosphorus; however, limited studies indicate that this phosphorus remains bound by the soil particles and is not carried by runoff flows into the Flathead River system. Continuation of the ongoing trend of more intensive crop production and increased fertilizer use on Flathead Valley agricultural lands merits careful monitoring because of potential nutrient implications for the aquatic system.

Habitat Implications of Sediment Release

Significant increases in sediment production from land uses would jeopardize stream habitat for both aquatic insects and fish in the Flathead aquatic system. The addition of sediments simplifies the stream habitat by coating the bottom with fine materials and smoothing out the contours of the channel. Sediments can fill in the spaces between rocks and block access to the hyporheic zone beneath and lateral to the stream bottom, thus eliminating important habitats for many aquatic species. Sedimentation can also reduce the availability of food for aquatic insects. Early stages of almost all aquatic species feed on fine organic particles which settle to the bottom of pools and backwater areas. An increase in the amount of inorganic sediments would dilute the organic content of the stream bottom materials and thus reduce the availability of this critical food source. The reduced availability of this critical food source would likely be reflected in reduced aquatic insect populations.

Juvenile bull and cutthroat trout feed primarily on aquatic insects, and reductions in insect populations would necessarily reduce stream productivity for trout. Excessive amounts of fine sediment in spawning grounds fill in the spaces between the gravels of trout redds and severely restrict the water flow reaching the eggs. The lack of intragravel flow leads to a shortage of oxygen and a buildup of metabolic wastes, both factors which contribute to the death of the developing fish embryos. The specific relationships between incubation success of trout eggs and the fine sediment content of stream bottom materials is the subject of ongoing research and monitoring by the Montana Department of Fish, Wildlife and Parks and the U.S. Forest Service.

The limited number and concentrated distribution of bull trout spawning sites makes this native game fish highly susceptible to adverse population impacts from land-use activities. Riparian areas (those sites immediately adjacent to streams) are particuarly important to the conservation of stream water quality and habitat. Removal of riparian vegetation as part of timber harvest, road-building, subdivision, micro-hydropower construction, or other developments can result in bank erosion and loss of spawning habitat.

Land-Use Proposals and Aquatic Resources in the Flathead Drainage

The impacts of human activities on the Flathead aquatic system can be expected to increase significantly during the next several decades based on the multitude of resource development proposals. The proposed coal mine at the junction of Cabin and Howell Creeks in British Columbia represents the largest land distrubance now under consideration in the Flathead drainage. Potential impacts on water quality, aquatic habitat, fish populations, and riparian habitat extend from the mine site downstream to Flathead Lake. A review of the water-related concerns expressed by the State of Montana in its official comments to the British Columbia government outlines the shortcomings of the mine proposal and the need for continued vigilance by concerned citizens to protect the Flathead watershed from adverse impacts. The Montana comments were based largely on research findings of the Flathead River Basin Environmental Impact Study.

The proposed coal development consists of two open pits, each of which will be developed to be one mile across by a thousand feet deep. Mine site development will include a processing plant, coal dryer, tailings ponds, haul roads, and other facilities which together will disturb about eight square miles of land. Waste rock from the mine will be collected in six huge spoils dumps, bordering over six miles of Cabin and Howell Creeks.

The inevitable contact between mine spoils and surface streams, groundwater flow, and ambient precipitation underlines the importance of careful water management at the mine site to protect downstream water quality. Although the mining plan is designed to channel water flow through a system of settling ponds, analysis by Montana hydrologists indicates that inflowing surface waters bolstered by groundwater may move through the settling ponds too rapidly to allow settling of sediments. If the effluent water contains the sediment levels allowed by Canadian water quality standards (50 milligrams of solid matter per liter), about 1,400 tons of sediment would be discharged into Howell and Cabin creeks each year. Supplemental calculations, based on the amount of land disturbance from the mine, indicate sediment discharge from the settling ponds could range as high as 14,000 tons per year.

The settling pond wastewater discharge would contain phosphorus in the sediments, along with dissolved nitrates, a residue of the intensive use of explosives. The phosphorus-containing sediments decanted from the settling ponds into the stream would generally be smaller than 10 microns in diameter, and thus most

Fording Coal Mine, Elkford, British Columbia would remain suspended in the stream current even during low flows. Researchers believe that fine sediments reaching Flathead Lake during the base-flow period of the Flathead River (normally a period of relatively low nutrient input) could significantly stimulate lake productivity and thus have adverse water quality impacts.

The high nutrient content in the settling ponds can also be expected to cause algal blooms, with the resulting bacterial decomposition of organic matter leading to anaerobic (lacking oxygen) waters. Anaerobic conditions could allow metals to dissolve from the mine waste rock.

Sedimentation at the mine site would severely impact the bull trout spawning area on Howell Creek adjacent to the mine site. Each year, this portion of Howell Creek hosts about 10% of all the spawning activity recorded for the migratory Flathead Lake bull trout population. Elimination of this spawning run and of the future recruitment of juvenile bull trout from Howell Creek to Flathead Lake would significantly reduce the bull trout population of the Flathead drainage. Partial stream dewatering due to mine interference with natural groundwater flows, along with anaerobic waters released from the settling ponds, would have major adverse impacts on the incubation success of bull trout in Howell Creek.

Montana officials have recommended that British Columbia adopt a mine site discharge standard of 15 mg/l of suspended solids (sediments) to offer some protection to bull trout spawning. The highest natural sediment discharge measured from Howell Creek was 14 mg/l during high water; thus the proposed 15 mg/l standard would not exceed the worst-case natural sediment loading. This standard would insure conformance with Montana's non-degradation standard for Class I Water Quality, which applies to the North Fork.

Montana officials have expressed strong concern about the physical location of the mine and the anticipated difficulties in reclamation. As proposed, the spoils dumps, mining pits, and settling ponds will be within 100 yards of the banks of Cabin and Howell creeks in many sites. The waste rock from the mine will be piled in huge, terraced dumps, some which will reach heights of more than 300 yards. The steep, bare slopes of unconsolidated materials are highly susceptible to massive slumping. Because of the height of the dumps and their proximity to the streams, such a waste dump failure could readily spread mine wastes across the adjacent streams. These instream spoils would serve as continual sources of sediments, nutrients, and toxic metals to the aquatic system.

Revegetation of the waste dumps promises to be extremely difficult due to the short growing season, the high precipitation, and the steepness of the slopes. Even if reclamation achieves a 90% reduction in sediment production, the mine site will still release 11,000 tons of sediment annually to the North Fork after the end of the 21-year mining operation. A 50% reclamation success would generate 60,000 tons of sediment annually, or a 40% increase over current levels of suspended soilds measured at the Canadian border.

Entry of this much sediment into the North Fork would initiate hydrological processes resulting in a broader, shallower stream bed with steeper banks. During spring runoff, this configuration would lead to higher flow levels, more severe bank erosion, and thus the transport of additional sediments and associated phosphorus to Flathead Lake.

The wide range of potential adverse impacts has led Montana specialists to conclude that the proximity of the waste dumps to the streams would severely jeopardize the integrity of the Flathead aquatic ecosystem.

The 50-year management plan for the Flathead National Forest proposes new road construction and timber harvest which will significantly increase water yield and sediment production from forested watersheds. Under the alternative preferred by the Forest Service, 32 of the 107 nonwilderness streams analyzed have the potential to experience water quality degradations in the first 10 years of plan implementation. Forest Service guidelines call for utilization of best management practices to mitigate water quality impacts associated with development. These practices include design and structural features to reduce surface erosion and staggered scheduling of timber harvests to prevent excessive water yield.

Forest Service projections for increased sediment yield do not include road construction or other surface disturbance associated with potential mineral or oil and gas development. The intensive timber and road development occurring in British Columbia is an additional potential source of increased sediment and water yield to the North Fork drainage.

The Federal Energy Regulatory Commission has received 26 proposals for the development of small-scale hydroelectric projects, most of which are located in streams in the Swan drainage. These dams on small tributary streams act as sediment traps which eventually have to be flushed, sending large amounts of sediment downstream. Small-scale hydro projects can also serve as a physical barrier for fish migrations, either by blocking access through damming or by

Coal storage facility, Fording Mine Elkford, British Columbia

routing of the stream through flumes and thus dewatering stream sections. The locations of proposed small-scale hydropower developments overlie some of the most important bull trout spawning areas in the Swan drainage.

Riparian Wildlife Habitat

Streamside or riparian zones comprise a very small percentage of the Flathead drainage, but provide critical seasonal habitat for a variety of wildlife species. The flat, low-lying flood plains are also readily accessible to man and have proven vulnerable to development. Agriculture, urban development, timber harvest, and transportation routes have altered riparian zones throughout the Flathead Basin. Only about 22% of the flood plain along the mainstem Flathead River above Flathead Lake retains its natural vegetation, while in the more remote North Fork, 88% of the habitat remains natural.

The Flathead River Basin Environmental Impact Study sponsored research to determine the river influences on the land environment, to map flood plain vegetative communities, and to document wildlife habitat use in the riparian zone. The findings provide management direction to conserve key wildlife habitat features and establish a baseline of current conditions against which future changes in vegetation and wildlife populations can be measured.

Big Game Winter Range in the North Fork Valley

The flood plain and adjacent upland terraces of the North Fork Valley provide food and cover for hundreds of deer, elk, and moose each winter. Habitat conditions within this winter range largely determine big game populations not only along the river bottom, but also in the high elevation summer and fall ranges in national forest lands west of the river, Glacier National Park lands east of the river, and in the British Columbia portion of the Flathead to the north. As land-use changes are contemplated within the North Fork drainage, a detailed understanding of winter range use becomes increasingly important to land managers, recreationists, and others interested in conserving populations of big game species.

Historical overview of big game populations in the North Fork. Numbers of deer, elk, and moose in the North Fork Valley have flucutated widely since the turn of the century. Several major wildfires from 1910 to 1930 removed forest overstory from extensive areas

Riparian area along mainstem Flathead River east of Kalispell

of the drainage and allowed shrubs to colonize the mountain slopes. White-tailed deer took advantage of the newly available winter forage and populations rose to an estimated 2,000 animals during the early 1930s. During the next two decades, however, the forest canopy recovered and the shrubs grew out of reach of the deer. The result was a population crash which continued until whitetail numbers stabilized at about 200 to 300 deer in the mid-1950s. Whitetail populations in the North Fork have remained within this range through the present time.

Elk populations, extremely low in the North Fork during the early 1900s, also increased in response to the vegetative changes caused by forest fires. Elk attained their greatest abundance about 20 years later than did whitetails. The regrowth of timber stands and the resultant decrease in the availability of shrubs has now reduced the elk population to less than half of its mid-1950s peak, and about 300 elk are estimated to inhabit the North Fork drainage.

Moose were reported to be considerably more abundant in the North Fork 50 years ago than today. Heavy illegal harvest and competition with elk are possible explanations for the current low population, estimated at less than 50 moose in the United States portion of the North Fork.

Vegetative communities in the winter range. The North Fork flood plain hosts a mosaic of different-aged plant communities, all of which represent stages in a succession from unvegetated river banks to mature forest. Plant community succession typically begins when leafy plants colonize cobble banks left dry by a change in the river course. Cottonwood saplings and willows, both adapted to the shallow soils and high-water tables, become established along the shoreline during the next several decades. Growth of the cottonwood trees eventually closes the forest canopy, and deeper soils develop through the deposition of leaf litter. Young spruce seedlings grow in the moist, shaded understory of the mature cottonwood community. A transitional community of mixed cottonwood and spruce typically persists for about 125 years. Gradually, the cottonwood trees die out and a climax community of mature spruce remains. Red osier dogwood and willows, both important winter foods for big game, are locally common shrub species in the understory of the cottonwood and spruce communities. Bank erosion, channel movement, fire, or floods can eliminate the mature forest stands and return the land to an earlier vegetational stage from which the successional development of plant communities will again begin.

Some areas of poor drainage, such as groundwater seeps or beaver ponds, maintain a stable shrub cover, rather than passing through the successional stages. Willow, alder, and ceanothus dominate this hydric shrub community, which is an extremely productive environment for these and other shrubs used by browsing big game animals in winter.

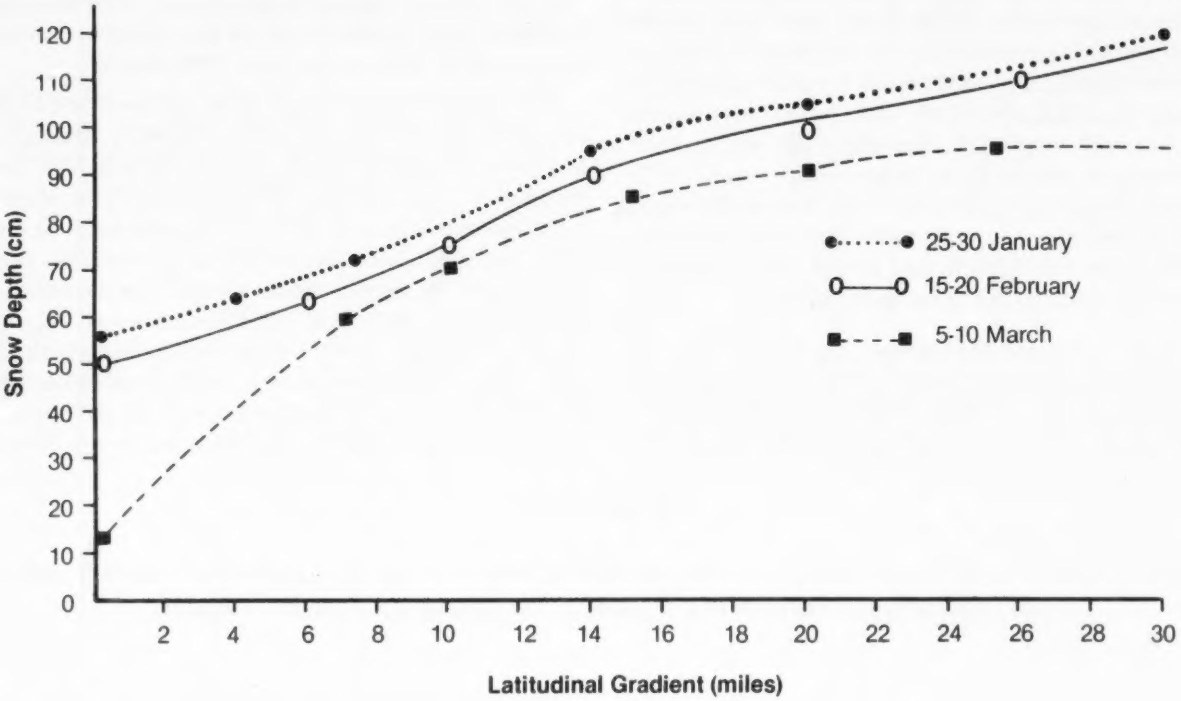
Extensive stands of lodgepole pine cover the upland terraces bordering the flood plain. Lodgepole forests take a variety of forms, including dense thickets of young trees, open savannahs with grass understory, and decadent older stands often infested by mountain pine beetles. Douglas-fir and western larch are common tree species in the relatively dry sites of the upland terrace, while mixed stands of subalpine fir and spruce occur in wetter areas.

Snow cover on the winter range. Snow depths along the North Fork increase steadily on a south-to-north gradient, with mid-winter readings in 1982 (an above-normal snow year) ranging from two feet at Big Creek up to four feet at the Canadian border. This pattern of snow depths corresponds to an elevational gain of 620 feet over the 31-mile distance. Snow was less persistent in southern sites, as warming temperatures and low-elevation rains reduced the early March snowpack to less than six inches at Big Creek, compared to the three feet of snow which remained at the border (Fig. 5.30).

Vegetative cover strongly influences snow depths in local areas. The greatest snow accumulations occur in clearcuts, natural meadows, and sparsely forested sites. As the forest canopy grows more dense, branches and needles intercept much of the snow. Subse-

FIGURE 5.30

Snow depths in open-growth floodplain communities along a latitudinal gradient, from Big Creek (Mile 1) to the Canada border (Mile 31). Sampling dates corresponded to periods of snow deposition (25-30 Jan.), maximum snow depth (15-20 Feb.), and early thawing (5-10 March).



quent solar heating of the tree surfaces often melts and evaporates the snow before it can fall to the ground. Snow is virtually absent beneath very dense stands of large trees because of this interception effect.

Big game distribution and habitat selection. White-tailed deer wintered primarily in the southern third of the North Fork corridor between Quartz Creek and Big Creek. This region was similar vegetatively to riparian areas to the north but was distinguished by lower snow depths. The few whitetails which used winter ranges in the northern two-thirds of the study area depended on wind-blown, south-facing slopes where snow depths were very low.

Within their limited geographic area, whitetails exhibited distinct preferences for specific vegetative cover types. Spruce flood plain forests accounted for over 60% of whitetail use, even though this habitat made up only about 20% of the cover in the whitetail winter range. Upland douglas-fir stands were also a preferred habitat. Open vegetation types, including young cottonwood stands, shrub patches, and meadows were used to only a limited extent, while large cutover areas were strongly avoided.

During the deep snow period of January and February, deer were most abundant in spruce stands having large trees and high tree densities (Fig. 5.31). The concerted use of such dense coniferous forest stands further indicates winter selection for structural habitats which offer relief from snow accumulations. As the snow cover receded in March, dense forest stands became less important and deer moved into feeding areas having large amounts of shrubs.

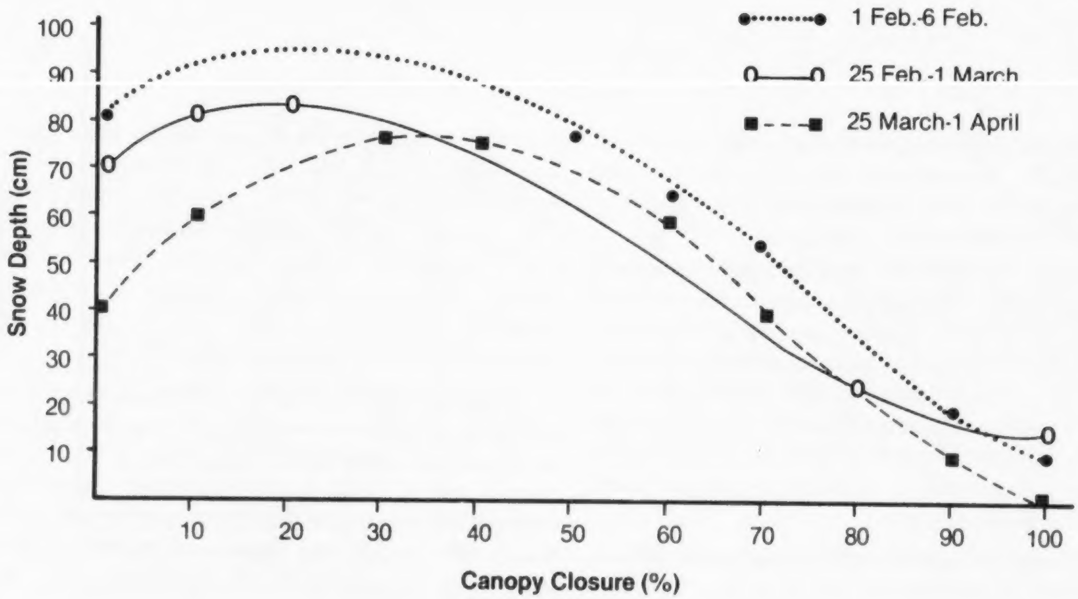
Elk winter throughout the North Fork, thus displaying a much wider geographic range than white-tailed deer. Local habitat selection by elk varied in response to snow conditions. In the northern two-thirds of the North Fork, elk favored timbered areas with relatively shallow snow depths, much like deer habitat preference to the south. Spruce bottomlands were a preferred habitat for elk and cutover areas were avoided. In the southern third of the North Fork, snow depths were more manageable for elk, and habitat selection was not significantly influenced by snow conditions. Along the flood plains, elk often fed in the younger successional vegetation, including the shrub wash, cottonwood, and cottonwood-spruce communities. In upland areas, elk preferred open lodgepole stands where bunchgrasses or black lichens were available. Dense upland douglas-fir and spruce stands were also important habitats in the northern sector.

Moose occurred throughout the North Fork, but track counts revealed moose to be eight times more abundant in the northern than the southern sector. Food availability, rather than snow depth, appeared to be the most important factor regulating moose distribution within the winter range. Moose demonstrated a strong preference for the hydric shrub and willow communities, and these sites contained the highest concentrations of the shrubs preferred for winter browsing. Bottomland spruce forests were heavily used for travel corridors and bedding sites. The most valuable wintering areas for moose were flood plain sites with spruce forests adjacent to shrub communities, thus providing cover and food in close proximity. On upland sites, moose occurred most commonly in lodgepole pine stands where the moose fed on young spruce and fir trees in the forest understory.

The intensive winter range surveys in the North Fork thus indicate that snow depth, vegetative structure, and food availability dictate the patterns of habitat use by deer, elk, and moose. Although flood plain communities constitute only 13% of the cover types in the river corridor, these communities contain the best combination of habitat requisites and sustain most of the winter use. Mature spruce forests are particularly important for deer and for elk in the northern parts of their winter range; moose key on the productive hydric shrub community, particularly when spruce forests are located nearby to provide necessary cover.

FIGURE 5.31

Snow depths in relation to forest canopy closure during periods of late deposition (1-6 Feb.), early melting (25 Feb. - 1 March) and late melting (25 March - 1 April).



Riparian area, North Fork Flathead River

Effects of flood plain timber removal on big game populations. Structural alteration of the flood-plain plant communities through logging or other development activities has the potential to decrease deer, elk, and moose populations by removing critical winter habitat components. As mature spruce and cottonwood trees are harvested, these flood plain sites revert to earlier successional stages composed largely of leafy plants, shrubs, or young cottonwood trees. The re-establishment of mature forests on these sites can take over 200 years, but during this interval uncut sites are also maturing into forest stands. The relationship between the loss of mature forests through logging and the growth of new forest stands through natural successional processes plays a critical role in determining the habitat suitability of the winter range for deer, elk, and moose. To estimate how timber harvest might affect deer, elk, and moose populations, researchers assessed the existing composition of the flood plain plant communities, the rate of succession from one community to the next, and the importance of each habitat to deer, elk, and moose. A mathematical model was then developed showing how the proportion of different plant communities would change over time through natural succession combined with timber harvest. Computer simulations of habitat changes and associated population impacts were based on hypothetical initial populations of 500 white-tailed deer, 100 elk, and 50 moose.

The results of this modeling effort indicate that white-tailed deer populations would prove most susceptible to tree removal in the flood plain, while moose and elk would be less affected. Logging 25% of the spruce and spruce-cottonwood stands over a 40-year period would drop deer populations from 500 to 400; a 50%-cleared area would only leave enough winter habitat to support 300 whitetails. Cessation of logging during the next 100 years, however, would allow populations to recover to pre-logging levels as the undisturbed young cottonwood communities developed a mature spruce overstory.

Annual timber harvest of either 5% of the mature spruce or 5% of the both spruce and spruce-cottonwood stands would have more lasting adverse effects on big game populations (Fig. 5.32). Under both regimes, whitetail numbers would drop sharply before leveling off well below the initial population of 500. This leveling off occurs when natural vegetative succession begins producing the flood plain forest communities at the same rate at which they are being harvested.

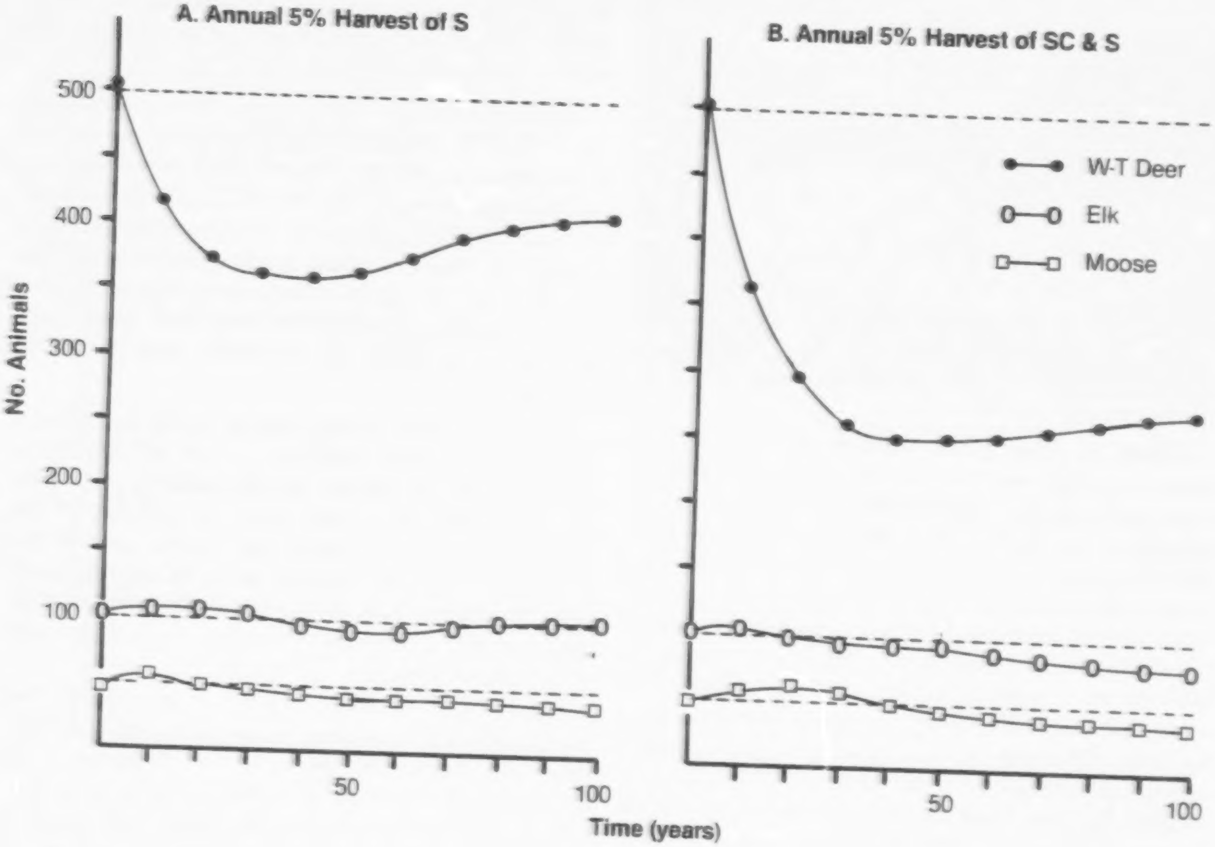
Both moose and elk populations would experience significant declines under an annual regime of 5% harvest of the spruce and spruce-cottonwood forests. Elk population reductions would be greatest in the northern end of the winter range, where snow depths are great enough to restrict elk to densely forested sites. The anticipated moose population declines are related to the requirement for forest cover near areas of high shrub density.

The validity of these population simulations has been indicated by events in the Swan River Valley, where clearcutting has altered 45% of the winter range and caused an estimated 50% decline in winter populations of white-tailed deer. One management option to allow timber harvest, yet prevent sharp reductions in big game winter habitat is selective cutting. A properly designed harvest system could remove some timber, but retain enough of the old-growth spruce forests to provide relief from excessive winter snow depths. Researchers have also suggested minimizing disturbance of the shrub communities that provide the bulk of big game winter forage.

Maintenance of existing spruce stands will not by itself insure long-term conservation of riparian winter range. Channel movement, fire, and old age will continue to eliminate mature spruce stands, even if timber harvest can be controlled. Thus, managers need to recognize the dynamic nature of flood plain vegetation and act to conserve adequate acreage of younger plant communities, such as the mature cottonwood and cottonwood-spruce forests, to generate replacement spruce forests as existing stands are lost.

FIGURE 5.32

Projected response of white-tailed deer, elk and moose to a 5% harvesting rate of spruce stands (A) and spruce-cottonwood stands (B). Dashed lines indicate equilibrium densities of cervids in the absence of forest harvesting.



Major developments in the flood plain. The two large dams in the Flathead drainage have severely impacted riparian habitat. The reservoir behind Hungry Horse Dam flooded about 35 miles of productive wildlife habitat along the South Fork, including significant amounts of winter range. Drawdowns of the reservoir now expose miles of shoreline mudflats, which have little wildlife value.

Kerr Dam at the outlet of Flathead Lake has played a major role in eliminating almost all of the delta peninsula and islands at the mouth of the upper Flathead River. These lands, built up by river-deposited sands, were normally flooded only during the spring high-water period and sustained extensive shoreline marshes, grading inland to forest cover. Bald eagles, osprey, waterfowl, white-tailed deer, and many other wildlife species used the delta habitats. The completion of Kerr Dam in 1938 allowed unnaturally high water levels to be maintained in Flathead Lake through most of the year. As a result, high waves from fall and winter storms have been able to erode the unstable sandy soils of the delta deposits. Nearly all of the 2-mile-long, 1½-mile-wide delta habitat has now been lost to erosion; additionally, high lake levels have eliminated the productive marsh habitat visible in historic photographs of other shoreline areas on Flathead Lake.

The detailed flood plain maps of the North Fork and the mainstem Flathead River prepared through the Flathead River Basin Environmental Impact Study will allow biologists to monitor natural and man-induced changes in the flood plain habitat. Future trends in wildlife populations can be related to land-use changes, allowing corrective management to be implemented if necessary.

Bird Habitat Use Along the Flathead River Flood Plain

Researchers reported 63 breeding bird species at survey sites along the North Fork and mainstem Flathead River flood plains during the summer of 1982. Characteristic birds of the various cover types in the Flathead flood plains include killdeer and spotted sandpiper in the herbaceous wash community; white-crowned sparrow in the shrub wash; dusky flycatcher and red-eyed vireo in mature cottonwood; dark-eyed junco in the spruce-cottonwood forest; golden-crowned kinglet, song sparrow, and townsend's warbler in mature spruce; and willow flycatcher, lincoln's sparrow, and a variety of wood warblers in the hydric shrub habitat. Thirty-four of the 63 species were restricted to one or two of the six different cover types. The robin, Hammond's flycatcher, and pine siskin were common species that displayed a very broad range of habitat use.

The number of bird species depended on the complexity of the vegetation. Sites lacking tree cover had six or fewer species, while all sites with trees held 11 or more species. Trees provided an additional habitat layer for nesting, foraging, and cover, and thus allowed more species to utilize a site. The density of birds increased as the percentage of shrub cover increased. The hydric shrub community was by far the most productive habitat, holding up to 45 birds per hectare (18 birds per acre).

Riparian areas in the Flathead River system provide excellent nesting habitat for great blue heron, osprey, and the endangered bald eagle. During 1982, biologists located five heron rookeries with 74 nests on the North Fork and the mainstem Flathead River from the Canadian border to Flathead Lake. Thirty-one active osprey nests were recorded, and most of these occurred between Kalispell and Flathead Lake. This 20-mile section is believed to hold the highest density of nesting osprey in Montana. Four bald eagle nests were active along the North Fork and the mainstem Flathead River during 1982. Herons, osprey, and eagles are highly sensitive to disturbance, and future development in the floodplain will have to leave a sizable buffer zone around nest sites if these unique species are to continue to breed successfully in the Flathead Basin.

Flathead River south of Highway 2 bridge, Kalispell

Monitoring Land Use in the Flathead Basin

The effect of land uses on lake water quality and stream habitat underscores the need for careful monitoring of the Flathead aquatic environment. The preceding subchapters have outlined the specific recommendations made by researchers for monitoring critical environmental components affecting river, lake and fisheries resources; the Landsat project, employing satellite imagery, offers an opportunity to monitor land uses on a broad scale throughout the Flathead drainage.

The Landsat satellite, operated by the National Aeronautics and Space Administration (NASA), orbits the earth at an altitude of 560 miles and utilizes specialized sensors to scan the earth surface. Computers analyzing Landsat images can distinguish 1-acre plots, including a variety of timber stands, agricultural operations, and urban development.

A Landsat project initiated as a one-time inventory by the Flathead River Basin Environmental Impact Study has recently been taken over and expanded by the Flathead National Forest and Glacier National Park. This project is designed to meet specific land management needs—for example, mapping and tabulating acreage of key grizzly bear habitat or high-risk forest fire sites. Because Landsat requires only a fraction of the money and manpower of on-the-ground surveys, cover type inventories can be updated annually.

Development of the Landsat data base will catalogue land uses and allow future comparisons of how the regional environment is changing. Resource managers, researchers and the public will thus be able to monitor the Flathead Basin watershed.

To conserve the natural values of the Flathead aquatic ecosystem, basin-wide monitoring will have to be accompanied by responsive land management. Researchers working through the Flathead River Basin Environmental Impact Study have now developed a solid understanding of the operation of the aquatic ecosystem and the influence of land uses on it. These findings can indicate ways to modify and refine resource management decisions to reduce adverse water quality impacts.

Several factors, however, stand in the way of directly applying the resource information base to land management decisions. The complex mosaic of land management jurisdictions in the Flathead Basin, coupled with sometimes inconsistent management objectives, often leads to conflicting activities within a single drainage basin. The multitude of natural resource development proposals also complicates management responsive to the needs of the aquatic system. Both major disturbances, such as the proposed Cabin Creek coal mine, and individually minor but collectively important activities, such as timber harvest, urban development, and agriculture, have the potential to cause major changes in the Flathead environment.

The 1983 session of the Montana Legislature has recognized the importance and the difficulties of maintaining the high quality environment of the Flathead drainage by passage of legislation creating a permanent governmental body to oversee the Flathead Basin environment (Appendix D). The newly established Flathead Basin Commission will serve as a forum for dialogue between all parties involved in land and resource management in the Flathead Basin. The commission will play key roles in monitoring the basin environment, scrutinizing resource management, and disseminating information. Thoughtful direction from the Flathead Basin Commission, based on knowledge of the ecosystem operation, will provide the means to meet the challenges of protecting the environment and related economic values, while maintaining opportunities for natural resource development. All of the people of the Flathead Basin will need to be part of this important public process.

Steering Committee for the Flathead River Basin Environmental Input Study overlooking site of proposed Cabin Creek coal mine, British Columbia

Goals and Objectives
Flathead River Basin Environmental Impact Study

Recognizing the unique natural attributes of the Flathead River Basin and the national significance of these attributes, the overall goal of the Flathead River Basin Environmental Impact Study is to enhance the existing "quality of life" found in the Flathead River Basin while maintaining and protecting a clean and healthful environment.

Objectives

To identify all existing water, land, air and socio-cultural data on the Basin and to compile this data into a format which is readily useable by resource managers, government officials and the general public.

To develop a scientifically reliable baseline of the water, land, air and socio-cultural conditions of the Basin.

To comprehensively assess the condition of the resource base of the Basin while striving to avoid duplication of this effort.

To develop a means to predict impacts of man's activities within the system in order to plan for resource utilization rather than to accomodate development.

To develop a tool to assess resource management alternatives and to adequately identify "trade-offs" and their effect on the quality of the Basin.

To develop the capability to predict the effects of resource utilization rather than to simply monitor development.

To evaluate and analyze the existing land management systems being utilized to effectuate resource utilization within the Basin.

To encourage the development of a compatible resource data base to be utilized, maintained and updated by all resource managers within the Basin.

To act as the catalyst to provide a coordination of study efforts in the Basin so as to work towards an integrated resource data assessment.

To develop comprensive management recommendations to guide future resource utilization within the Basin.

To identify and document the process to accomplish this Study.

Water Quality Goal

To maintain and enhance the ecological integrity of the aquatic environments within the Flathead River Basin.

Objectives

To identify and then quantify the existing critical chemical, physical, and biological requirements of the waters of the Basin.

To identify areas of the Basin where man's activities may significantly affect water quality including but not limited to floodplains, wetlands, riparian areas, areas with high groundwater, recharge areas, and critical groundwater areas.

To determine how man's activities are influencing the amount of nutrients entering Flathead Lake.

To quantify the role that sedimentation has on the quality of Flathead Lake.

To identify bays, channels or other areas of Flathead Lake which are susceptible to environmental degradation.

To identify existing or potential water quality problem areas of the Basin and to identify the parameters causing the problem.

To quantify the critical habitat requirements of the fisheries of the Basin, paying particular attention to the habitat requirements of the West Slope Cutthroat Trout and the Dolly Varden.

To determine the minimum quantities of water required to maintain cold water fisheries in the Basin.

To determine the temperature requirements of the existing biotic community with special attention to the fisheries resources.

To establish guideline for the protection of the aquatic environment.

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Land Resource Goal

To manage the land resource so as to protect and enhance the ecological integrity of the Flathead River Basin.

Objectives

To encourage the identification of the landforms, bedrock geology and soils through mapping of the entire Basin.

To identify the location and amount of erosion occurring within the Basin and to determine the erosion potential of the Basin.

To identify within each sub-basin the types and amounts of erosion that can occur without adversely affecting the water system.

To determine which of man's activities and how much each of these activities is contributing to sedimentation and nutrient loading of the river system.

To set guidelines regarding limits for sedimentation and nutrient loading of the river system and to utilize these guidelines to influence man's activities.

To identify the habitat requirements and existing condition of the wildlife of the Basin.

To identify and quantify critical habitat areas of the wildlife of the Basin.

To identify and assess the status and habitat requirements of wildlife species which provide indicators of the quality of the environment and to then monitor the health of these species in the system.

To identify the tolerance of the wildlife in the Basin to various types of man's activities.

To develop guidelines to insure that the existing extent and diversity of wildlife is maintained and/or enhanced within the Basin.

To identify critical areas where land uses would irretrievably commit water, land, air and socio-cultural resources to the detriment of the Basin considering the incremental nature of these actions.

To develop guidelines which set parameters for the level of development which may take place considering erodibility, habitat protection, nutrient release and physical stream requirements in order to maintain or enhance the ecological integrity of the Basin.

Air Quality Goal

To maintain and enhance the air quality which exists within the Flathead River Basin.

Objectives

To quantify the existing air quality within the Basin.

To identify existing levels and sources of air pollution which affects the Basin.

To quantify the meteorology of the Basin at both low and high altitudes.

To develop the capability to assess the affects of man's activities upon the air quality of the Basin.

To develop guidelines to protect and enhance the air quality of the Basin.

Socio-cultural Goal

To maintain a viable, resource based rural lifestyle within the Flathead Rvier Basin.

Objectives

To identify the desire of the residents of the Basin and to determine what values the residents attribute to the water, land, air and socio-cultural resources of the Basin in their definition of "quality of life".

To recognize the cultural and historical resources of the Basin.

To quantify the existing economy of the Basin.

To develop a quantitative procedure to assess both the positive and negative effects of man's activities on the economy of the Basin.

To describe the social structure of the various areas of the Basin.

To identify existing resource development activities and to relate the importance of these developments on the present life styles in the Basin.

To identify existing and potential health hazards within the Basin.

To identify the visual resources of the Basin with emphasis on unique visual resources.

Glossary

acre-foot — the volume that would cover one acre to a depth of one foot.

adfluvial — fish which reside in lakes and migrate upstream to spawn in tributary rivers or streams.

algal bloom — a rapid increase in the algae population, often related to the increased availability of nutrients.

alluvial — pertaining to materials transported or deposited by water.

aquifer — a water-bearing, subsurface layer of rock, sand, or gravel.

benthic — relating to or inhabiting the stream bottom.

diapause — a period of time in the insect life cycle during which development temporarily ceases.

ecology — the pattern of relations between organisms and their environment.

ecosystem — the complex of a biological community and its environment which functions as a unit in nature.

eutrophic — characterizing a body of water having high nutrient concentrations, high levels of plant productivity, and generally poor water quality.

hyporheic zone — an area of loosely compacted, groundwater-saturated gravels lying adjacent to or beneath a stream channel.

instar — a stage in the life of an insect between successive molts.

inversion (temperature inversion) — a condition characterized by air temperatures increasing with increasing height above the ground.

microgram — a unit of weight equal to one millionth of a gram.

micron — a unit of length equal to one millionth of a meter.

nonpoint sources — a dispersed collection of minor air or water pollution sources.

oligotrophic — characterizing a body of water having low nutrient concentrations, low levels of plant productivity, and high water quality.

organic detritus — fine, nonliving particulate material of plant or animal origin.

photosynthesis — the production of biochemical compounds by plants using energy from sunlight.

phytoplankton — the collection of free-floating microscopic plants inhabiting a body of water.

point source — an isolated or well-defined producer of air or water pollution, such as an industrial smokestack or a sewage plant.

redd — the spawning bed of a fish.

riparian — relating to a streamside or lakeshore region.

Tertiary period — a geologic time span, between 3 and 40 million years ago, characterized by dry climate and the deposition of deep beds of weathered bedrock on the valley floors in the Rocky Mountain region.

till — unstratified glacial deposits consisting of intermingled clay, sand, gravel, and boulders.

zooplankton — the collection of tiny animals inhabiting the water column.

BIBLIOGRAPHY — STUDY RELATED PUBLICATIONS*

Appert, S. 1980. Ecological Studies on the Effects of Regulation on the Macroinvertebrates in the Flathead River, Western Proceedings, 60th Annual Conference of the Western Association of Fish and Wildlife Agencies.

Bauman, B. J. and W. M. Schafer. 1983. Permeability of Flathead Basin Soils: Determining Suitability for On-site Waste Disposal-Final Report. U.S. Environmental Protection Agency, Montana Cooperative Extension Service and Montana State University, Bozeman, Montana.

Bodmer, S., and N. Stark. 1980. Final Report on Studies of Non-point Source Pollution in the Upper Flathead Drainage, U.S. Environmental Protection Agency, University of Montana, Missoula, Montana.

Coefield, J. A., J. W. Gelhaus, M.G. Machler, W. P. Campbell, H. W. Robbins, and A. T. Myren, Jr. 1981. Interim Annual Report for July 1979 through September 1980, Air Quality Investigations. U.S. Environmental Protection Agency, Montana Department of Health and Environmental Sciences, Helena, Montana, 55 pp.

Coefield, J. A. 1983. Interim Air Resources Report, U.S. Environmental Protection Agency, Montana Department of Health and Environmental Sciences, Air Quality Bureau, Helena, Montana.

Coefield, J. A. 1983. Final Air Resources Report, U.S. Environmental Protection Agency, Montana Department of Health and Environmental Sciences, Air Quality Bureau, Helena, Montana.

Decker-Hess, J. and P. J. Graham. 1982. Impacts of Water Level Fluctuations on Kokanee Reproduction in Flathead Lake, USDI Bonneville Power Administration, Montana Department Fish, Wildlife and Parks, Kalispell, Montana.

Eco-Northwest. 1982. The Flathead Basin: An Economic Assessment, U.S. Environmental Protection Agency, Montana Department of Administration, Helena, Montana, 186 pp.

Ellis, B. K. 1980. Size Fractionation of Metabolically Active Phytoplankton and Bacteria in Two Diverse Benthic Systems, M.S. thesis, North Texas State University, Denton, Texas.

Ellis, B. K. and J. A. Stanford. 1982. Comparative photolithotrophy, chemoheterotrophy and photolithotrophy in an eutrophic reservoir and an oligotrophic lake. Limnology and Oceanography 27(3): 450-454.

Fraley, J. J., D. Read and P. J. Graham. 1981. Flathead River Fishery Study-Annual Report, U.S. Environmental Protection Agency, Montana Department of Fish, Wildlife and Parks, Kalispell, Montana.

Fraley, J. J. and P. J. Graham. 1981. Physical Habitat, Geologic Bedrock Types and Trout Densities in Tributaries of the Flathead River Drainage, Montana. Proceeding of Acquisition and Utilization of Aquatic Habitat Information Symposium, Portland, Oregon.

Fraley, J. J. and P. J. Graham. 1982. Impacts of Hungry Horse Dam on the Fishery in the Flathead River—Final Report, USDI Bureau of Reclamation, Montana Department of Fish, Wildlife and Parks, Kalispell, Montana.

Fredenberg, W. and P. J. Graham. 1982. Flathead River Fishermen Census, U. S. Environmental Protection Agency, Montana Department of Fish, Wildlife and Parks, Kalispell, Montana.

Fredenberg, W. and P. J. Graham. 1982. Census of Kokanee Fishermen on the Flathead River, USDI Bureau of Reclamation, Montana Department of Fish, Wildlife and Parks, Kalispell, Montana.

Graham, P. J., J. J. Fraley, and D. Read. 1980. Flathead River Basin Fishery Study Annual Report, U.S. Environmental Protection Agency, Montana Department of Fish, Wildlife and Parks, Kalispell, Montana.

Graham, P. J., and S. L. McMullin. 1980. The Impact of Hungry Horse Dam on Aquatic Life in the Flathead River—Annual Report, USDI Bureau of Reclamation, Montana Department of Fish, Wildlife and Parks, Kalispell, Montana.

Graham, P. J., D. Hanzel and R. E. Schumacher. 1980. Kokanee Management in the Flathead System, Western Proceedings, 60th Annual Conference of the Western Association of Fish and Wildlife Agencies.

Graham, P. J. and B. B. Shepard, and J. J. Fraley. 1981. Use of Stream Habitat Classifications to Identify Bull Trout Spawning Areas in Streams, Proceeding of Acquisition and Utilization of Aquatic Habitat Information Symposium, Portland, Oregon.

Graham, P. J. and W. Fredenberg. 1982. Flathead Lake Fishermen Census, U.S. Environmental Protection Agency, Montana Department of Fish, Wildlife and Parks, Kalispell, Montana.

Hauer, F. R. and J. A. Stanford. 1982. Bionomics of *Dicosmoecus gilvipes* (Hagen) (Trichoptera: Limniphilidae) in a large montane river. American Midland Naturalist 108(1): 81-87.

Hauer, F. R. and J. A. Stanford. 1982. Ecological responses of hydropsychid caddisflies to stream regulation. Canadian Journal of Fisheries and Aquatic Sciences 39(9): 1235-1242.

Hauer, F. R. and J. A. Stanford. 1982. Ecology and Life Histories of Three Net Spinning Caddisfly Species (Hydropsychidae: Hydropsyche) in the Flathead Rivers, Montana. Freshwater Invertebrate Biology 1(4): 18-29.

Hauer, F. R. 1980. Ecological Studies of Trichoptera in the Upper Flathead Rivers, Montana, Ph.D. dissertation, North Texas State University, Denton, Texas.

Hauer, F. R., E. G. Zimmerman and J. A. Stanford. 1980. Preliminary investigations of distributional relationships of Aquatic insects and genetic variations of a fish population in the Kintla drainage, Glacier National Park, Montana. pp. 41-85. **IN:** Proc. 2nd Conf. on Sci. Res. in the National Parks, Vol. 2, Amer. Inst. Biol. Scie., Arlington, VA.

Hauer, F. R. and J. A. Stanford. 1982. Ecology and life histories of *Brachycentrus americanus* and *B. occidentalis (Trichoptera: Brachycentridae)* in the Flathead River, USA. Holarctic Ecology, submitted.

Henry, R. L., and J. A. Stanford. 1983. A Simulation Study of Phosphorus Dynamics in Flathead Lake, Montana, U.S. Environmental Protection Agency, University of Montana Biological Station, Bigfork, Montana.

Jiwan, J. and Moore, J. 1982. Distribution of phosphorus in the surface sediments of Flathead Lake, Montana: Geological Society of America, Abstracts with Program, Spring 1982 Rocky Mountain Section Meetings, Bozeman, Montana.

Leathe, S. A. and P. J. Graham. 1982. Flathead Lake Fish Food Habits Study—Annual Report, U.S. Environmental Protection Agency, Montana Department of Fish, Wildlife and Parks, Kalispell, Montana.

Leathe, S. A. and P. J. Graham. 1982. Flathead Lake Fish Food Habits Study, U.S. Environmental Protection Agency, Montana Department of Fish, Wildlife and Parks, Kalispell, Montana.

McMullin, S. L. 1980. Hydroelectric Peaking and Kokanee Salmon Year-class Strength—Historic Relationships in the Flathead, Western Proceedings, 60th Annual Conference of the Western Association of Fish and Wildlife Agencies.

McMullin, S. L. and P. J. Graham. 1981. The Impact of Hungry Horse Dam on the Kokanee Fishery of the Flathead River, USDI Bureau of Reclamation, Montana Department of Fish, Wildlife and Parks, Kalispell, Montana.

Mace, T. 1981. Airborne Multispectral Scanner Characterization of Lake Water Quality Parameters, Flathead Lake, Montana, U.S. Environmental Protection Agency, Las Vegas, Nevada.

Montana Department of Fish, Wildlife and Parks. 1979. North Fork of the Flathead River Fisheries Investigations, U.S. Environmental Protection Agency, Montana Department of Fish, Wildlife and Parks, Kalispell, Montana.

Montana Department of Fish, Wildlife and Parks. 1982. Fish and Habitat Inventory of Streams in the Middle Fork of the Flathead River, U.S. Evnironmental Protection Agency, Montana Department of Fish, Wildlife and Parks, Kalispell, Montana.

Montana Department of Fish, Wildlife and Parks. 1982. Instream Fish Flow Evaluation for the North Fork, Middle Fork and Mainstem of the Flathead River, U.S. Environmental Protection Agency, Montana Department of Fish, Wildlife and Parks, Kalispell, Montana.

Montana Department of Fish, Wildlife and Parks. 1982. Fish and Habitat Inventory of Streams in the North Fork of the Flathead River, U.S. Environmental Protection Agency, Montana Department of Fish, Wildlife and Parks, Kalispell, Montana.

Moore, J. J., J. S. Jiwan, C. Murray, S. M. Vike, B. D. Wall, and G. R. Thompson. 1981. Sedimentation in Flathead Lake, Montana—Annual Report: 1980, U.S. Environmental Protection Agency, University of Montana, Missoula, Montana.

Moore, J. J., J. S. Jiwan, C. Murray. 1982. Sediment Geochemistry of Flathead Lake, Montana, U.S. Environmental Protection Agency, University of Montana, Missoula, Montana.

Moore, J. J., Rubin, C. and Dea, P., 1980. Effects of changing water levels on a lacustrine delta complex, Flathead Lake, Montana: Geological Society of America, Abstracts with Program, v. 12, no. 6, p. 298.

Moore, J. J., et al. 1982. Controls of phosphorus migration by iron and manganese in the surface sediments of Flathead Lake, Montana, USA: Geological Society of Canada, Annual Meeting in Winnepeg, Spring 1982, Abstracts volumn.

Moore, J. J., in press. The origin of calcium carbonate nodules forming on Flathead Lake Delta, Montana: Limnology and Oceanography.

Murray, C. J. 1982. Heavy metal concentrations in the surface sediment of Flathead Lake, Montana: Geol. Soc. Amer., Abstracts with Program, Spring 1982 Rocky Mountain Section Meetings, Bozeman, Montana.

Perry, S. and P. J. Graham. 1981. The Impact of Hungry Horse Dam on the Aquatic Invertebrates of the Flathead River—Annual Report, USDI Bureau of Reclamation, Montana Department of Fish, Wildlife and Parks, Kalispell, Montana.

Perry, S. 1982. Impacts of Hungry Horse Dam on the Invertebrates in the Flathead River—Final Report, USDI Bureau of Reclamation, Montana Department of Fish, Wildlife and Parks, Kalispell, Montana.

Perry, S. 1982 (in draft). Effects of Regulation by High Dams on Benthic Ecology of the Flathead and Kootenay Rivers, Montana, Ph.D. dissertation, North Texas State University, Denton, Texas.

Perry, W. B., J. T. Boswell and J. A. Stanford. 1979. Critical problems with adenosine triphosphate (ATP) assays of planktonic biomass. Hydrobiol. 65: 155-163.

Perry, W. B. and J. A. Stanford. 1982. Algal Growth stimulus by phosphorus in Flathead Lake, Montana sediments. Northwest Science 56(1): 48-52.

Potter, D. S. and J. A. Stanford. 1975. Influences on plankton communities of oligotrophic Flathead Lake. Verh. Internat, Limnol. 19: 1790-1797.

Read, D. 1980. Movement of Westslope Cutthroat and Bull Trout in the Upper Flathead River Western Proceedings, 60th Annual Conference of the Western Association of Fish and Wildlife Agencies.

Read, D., B. Shepard, and P. J. Graham. 1982. Fish and Habitat Inventory of Streams in the North Fork of the Flathead River, U.S. Environmental Protection Agency, Montana Department of Fish, Wildlife and Parks, Kalispell, Montana.

Rockwell, D. B., J. A. Roach and K. Espeseth. 1981. Flathead River Basin Bibliography, U.S. Environmental Protection Agency, Montana Department of Natural Resources and Conservation, Helena, Montana.

Shepard, B. and P. J. Graham. 1982. Completion Report—Monitoring Spawning Bed Material Used by Bull Trout on the Glacier View District, Flathead National Forest, USDA Forest Service, Region I, Montana Department of Fish, Wildlife and Parks, Kalispell, Montana.

Shepard, B., J. J. Fraley, T. Weaver and P. J. Graham. 1982. Flathead River Fisheries Study—Annual Report, U.S. Environmental Protection Agency, Montana Department of Fish, Wildlife and Parks, Kalispell, Montana.

Shepard, B. B. and P. J. Graham. 1983. Program to Monitor the Fish Resources of the Upper Flathead Basin, U.S. Environmental Protection Agency, Montana Department of Fish, Wildlife and Parks, Kalispell, Montana.

Stanford, J. A. 1973. A centrifuge technique for determining live weights of aquatic insect larvae with a note on weight loss in preservative. Ecology 54(2): 449-451.

Stanford, J. A. and E. B. Reed. 1974. A basket sampling technique for quantifying riverine macrobenthos. Water Resources Bulletin 10: 470-477.

Stanford, J. A. and A. R. Gaufin. 1974. Hyporheic communities of two Montana rivers. Science 185: 700-702.

Stanford J. A. 1975. Ecological studies of Plecoptera in the upper Flathead and Tobacco Rivers, Montana. Ph.D. dissertation. University of Utah, Salt Lake City. 214 pp.

Stanford, J. A. and D. S. Potter. 1976. The Flathead Lake-River ecosystem: a perspective. pp. 241-250. **IN:** R. Soltero (Ed.) Proceedings of ESA Symposium on Aquatic and Terrestrial Research in the Pacific Northwest. Cheney, Washington. 397 pp.

Stanford, J. A. and F. R. Hauer. 1978. Preliminary observations on the ecological effects of flow regulation in the Flathead Rivers, Montana. Report to U.S. Bureau of Reclamation. Boise, Idaho.

Stanford, J. A. and J. V. Ward. 1979. Stream regulation in North America. pp. 215-236. **IN:** J. V. Ward and J. A. Stanford (Eds.) The Ecology of Regulated Streams. Plenum Press, New York. 398 pp.

Stanford, J. A. 1979. Proliferation of river deltas in reservoirs: a "natural" mitigative process? **IN:** C. A. Swanson (Ed.) The Mitigation Symposium: A National Workshop on Mitigating Losses of Fish and Wildlife Habitats. Gen. Tech. Rept. RM-65, Rocky Mountain Forest Range Experimental Station, USDA. Fort Collins, Colorado.

Stanford, J. A., F. R. Hauer, T. J. Stuart, B. K. Ellis and W. B. Perry. 1980. Limnology of the Flathead River-Lake ecosystem, Montana. Annual Report. U.S. Environmental Protection Agency, University of Montana Biological Station. Bigfork, Montana. 440 pp.

Stanford, J. A., T. J. Stuart, J. D. Coulter, and F. R. Hauer. 1981. Limnology of the Flathead River-Lake Ecosystem, Montana: annual report. U.S. Environmental Protection Agency. University of Montana Biological Station. Bigfork, Montana. 301 pp.

Stanford, J. A., T. J. Stuart, and B. K. Ellis. 1983. Limnology of Flathead Lake: Final Report, U.S. Environmental Protection Agency, University of Montana Biological Station, Bigfork, Montana.

Stanford, J. A., F. R. Hauer and J. D. Coulter. 1983. Limnology of Flathead River: Final Report, U.S. Environmental Protection Agency, University of Montana Biological Station, Bigfork, Montana.

Stanford, J. A., R. L. Henry, B. K. Ellis and S. B. Berte. 1982. Limnology of the Flathead River-Lake ecosystem, Montana: annual report. U.S. Environmental Protection Agency, University of Montana Biological Station, Bigfork, Montana. 42 pp.

Stanford, J. A. and J. V. Ward. 1983. Insect species diversity as a function of environmental variability and disturbance in stream systems. **IN:** Barnes, J. and G. Minshall (Eds.) Applications of Ecological Theory to Running Waters. Plenum Press, New York. (In Press).

Stanford, J. A. and A. R. Gaufin. 1983. Ecology and life histories of Plecoptera in the Flathead Rivers, Montana. Submitted to Arch. Hydrobiol. Suppl.

Staurt, T. J. 1982. The Effects of Freshet Turbidity on Selected Aspects of the Biogeochemistry and the Trophic Status of Flathead Lake, Montana, Ph.D. dissertation North Texas State University, Denton, Texas.

Sutherland, R. J. 1982. Recreation and Preservation Valuation Estimates for Flathead River and Lake System, U.S. Environmental Protection Agency, Helena, Montana.

Tibbs, J. F., A. R. Gaufin and J. A. Stanford. 1975. Distribution and biotic effects of nutrients in Flathead Lake, Montana. Report to Environmental Protection Agency and State of Montana Department of Health and Environmental Sciences. 45 pp.

U.S. Geological Survey. 1978. Evaluation and Correlation of Water Quality Data for the North Fork Flathead River, Northwestern Montana, Water Resources Investigations 78-111, Helena, Montana.

Ward, J. V. and J. A. Stanford. 1979. Limnological considerations in reservoir operation: optimization strategies for the protection of aquatic biota in the receiving stream. **IN:** G. A. Swanson (Ed.) The Mitigation Symposium: A National Workshop on Mitigating Losses of Fish and Wildlife Habitats. Gen. Tech. Rept. RM-65, Rocky Mountain Forest Range Exp. Sta., USDA, Fort Collins, Colorado.

Ward, J. V. and J. A. Stanford. 1979. Ecological factors controlling stream zoobenthos with emphasis on thermal modification of regulated streams. pp. 35-56. **IN:** J. V. Ward and J. A. Stanford (Eds.) The Ecology of Regulated Streams. Plenum Press, New York. 398 pp.

Ward, J. V. and J. A. Stanford. 1981. Tailwater biota: ecological response to environmental alterations. pp. 1516-1525. **IN:** Stefan, H. G. (Ed.) Proc. of the Symp. on Surface-Water Impoundments, American Society of Civil Engineers, New York.

Ward, J. V. and J. A. Stanford. 1982. Effects of reduced and pertubed flow below dams on fish food organisms in Rocky Mountain trout streams. American Fishery Society, Special Publication, in press.

Ward, J. V. and J. A. Stanford. 1982. Effects of reduced and perturbated flow below dams on fish food organism in Rocky Mountain trout streams. p. 493-501. **IN:** J. H., Grover (Ed.), Allocation of Fishery Resources. FAO, Rome, Italy.

Ward, J. V. and J. A. Stanford. 1983. The serial discontinuity concept of lotic ecosystems. p. 29-42. **IN:** Fontaine, T. D. III and S. M. Bartell (Eds.) Dynamics of Lotic Ecosystems. Ann Arbor Science, Ann Arbor, Michigan.

Ward, J. V. and J. A. Stanford. 1982. Thermal responses in the evolutionary ecology of aquatic insects. Ann. Rev. Entomology, 27: 97-117.

Ward J. V. and J. A. Stanford (Eds.) 1979. Ecology of Regulated Streams. Plenum Press, New York, New York.

Ward, J. V. and J. A. Stanford. 1983. The intermediate disturbance hypothesis: an explanation for biotic diversity patterns in lotic ecosystems. p. 347-356. **IN:** Fontaine, T. D. III and S. M. Bartell (Eds.) Dynamics of Lotic Ecosystems. Ann Arbor Science, Ann Arbor, Michigan.

Ward, J. V. and J. A. Stanford. 1983. The regulated stream as a testing ground for ecological theory. **IN:** Lillehammer, A. and S. Saltveit (Eds.) Ecology of Regulated Streams II. Univeristy of Oslo Press, Oslo, Norway. (In Press).

Western Analysis Inc. 1982. Flathead River Basin Fiscal Impact Study: An Assessment of Future Fiscal Conditions in Nine Taxing Jurisdictions, U.S. Environmental Protection Agency, Montana Department of Administration, Helena, Montana, 81 pp.

Wright, G. R., K. Jenkins, B. Butterfield, C. Key, and P. Happe. 1983. Riparian Habitat Study North Fork and Mainstem Flathead River, Montana Final Report, U.S. Environmental Protection Agency, Cooperative Parks Studies Unit, University of Idaho, Moscow, Idaho, 195 pp.

*NOTE: Citations listed relate to Flathead River Basin, but research has not necessarily been financed by U.S. Environmental Protection Agency.

Bill Creating Flathead Basin Commission

AN ACT TO ESTABLISH A FLATHEAD BASIN COMMISSION TO COORDINATE MONITORING OF THE QUALITY AND CONDITIONS OF FLATHEAD LAKE AND THE NATURAL RESOURCES WITHIN THE FLATHEAD BASIN; AND PROVIDING AN EFFECTIVE DATE.

WHEREAS, Flathead Lake is the largest natural body of fresh water in the continental United States west of the Mississippi River and is a significant natural resource of value statewide and in the Northwestern region of the United States; and

WHEREAS, research undertaken as part of the Flathead River basin environmental impact study demonstrates that the quality of the Flathead Lake aquatic environment is vulnerable to and affected by all forms of land use and resource development within the Flathead basin; and

WHEREAS, even though the Flathead Lake aquatic environment is of excellent quality, the cumulative impact of a wide variety of resource development activities poses a threat to the aquatic environment of the Flathead basin; and

WHEREAS, protection of this natural resource is complicated by overlapping and potentially conflicting international, state, provincial, tribal, and local jurisdictional interests and responsibilities, which require awareness, coordinated effort, shared responsibility, and devotion to the naturalness of the basin by each land and water management entity with responsibility in the basin.

BE IT ENACTED BY THE LEGISLATURE OF THE STATE OF MONTANA:

Section 1. Short title. [This act] may be cited as the "Flathead Basin Commission Act of 1983".

Section 2. Purpose. The purpose of the Flathead basin commission is to protect the existing high quality of the Flathead Lake aquatic environment; the waters that flow into, out of, or are tributary to the lake; and the nautral resources and environment of the Flathead basin.

Section 3. Definitions. As used in [this act], the following definitions apply:

(1) "Aquatic resources" means all beneficial uses of water, including but not limited to water quality and water supply; recreational, scenic, and aesthetic values; and fish, wildlife, and other organisms.

(2) "Commission" means the Flathead basin commission esablished in [section 4].

(3) "Flathead basin" means all land and water areas the water from which drains into Flathead Lake or its tributaries.

Section 4. Flathead basin commission—membership—compensation. (1) There is a Flathead basin commission.

(2) The commission consists of 15 members selected as follows:

(a) four members appointed by the governor from industrial, environmental, and other groups affected by [this act], one of whom must be on the governor's staff and who also serves as the executive director;

(b) one member who shall be the commissioner of state lands or his designee;

(c) one member appointed by the Flathead County commissioners;

(d) one member appointed by the Lake County commissioners;

(e) one member appointed by the Confederated Salish and Kootenai Tribes;

(f) one member appointed by the United States department of agriculture, forest service regional forester for the northern region;

(g) one member appointed by the United States department of interior national park service, regional director for the Rocky Mountain region;

(h) five ex officio members appointed respectively by the chief executive of the provincial government of the Province of British Columbia, the regional administrator of the United States environmental protection agency, the administrator of the Bonneville Power Administration, the chief of engineers of the United States army corps of engineers, and the holder of a license issued for the Flathead project under the Federal Power Act.

(3) The commissioners shall serve without pay. Commissioners, mentioned in section 4(2)(a), except the commissioner on the governor's staff, are entitled to reimbursement for travel, meals, and lodging while engaged in commission business, as provided in 2-18-501 through 2-18-503.

(4) The commission is attached to the governor's office for administrative purposes only.

Section 5. Term of appointment—quorum—vacancy—chairman—vote. (1) The commission members shall serve staggered 4-year terms.

(2) A majority of the membership, other than ex officio members, constitutes a quorum of the commission.

(3) A vacancy on the commission must be filled in the same manner as regular appointments, and the member so appointed shall serve for the unexpired term to which he is appointed.

(4) The commission shall select a chairman from among its members. The chairman may make motions and vote.

(5) A favorable vote of at least a majority of all members, except ex officio members, of the commission is required to adopt any resolution, motion, or other decision of the commission.

Section 6. Commission staff and office location. (1) The executive director of the commission shall be compensated on a pro rata basis from commission funds, calculated upon the time he is required by the governor to serve the commission.

(2) An office for the commission may be established at a community located in the basin, and sufficient and appropriate staff must be assigned to serve the commission.

Section 7. Duties of the commission. Duties of the commission are:

(1) to monitor the existing condition of natural resources in the basin and coordinate development of an annual monitoring plan. This plan must involve a cooperative strategy among all land and water management agencies within the Flathead basin and identify proposed and needed monitoring which emphasizes but is not limited to the aquatic resources of the Flathead basin.

(2) to encourage close cooperation and coordination between federal, state, provincial, tribal, and local resource managers for establishment of compatible resource development standards, comprehensive monitoring, and data collection and interpretation;

(3) to encourage and work for international cooperation and coordination between the state of Montana and the Province of British Columbia concerning the undertaking of natural resource monitoring and use of consistent standards for management of resource development activities throughout the North Fork Flathead River drainage portion of the Flathead basin;

(4) to encourage economic development and use of the basin's resources to their fullest extent without compromising the present high quality of the Flathead basin's aquatic environment;

(5) to, in the discretion of the commission, undertake investigations of resource utilization and hold public hearings concerning the condition of Flathead Lake and Flathead basin;

(6) to submit a biennial report to the governor and the appropriate committees of the legislature that includes:

(a) a summary of information gathered in fulfillment of its duties under this section;

(b) information on monitoring activities within the Flathead basin concerning the condition of the basin's natural resources, with particular emphasis on Flathead Lake;

(c) the identification of land use and land development trends in the Flathead basin;

(d) any recommendations the commission considers appropriate for fulfillment of its duties and for continued preservation of the Flathead basin in the present high quality of its aquatic resources; and

(e) an accounting of all money received and expended, by source and purpose, for the period since the last report; and

(7) to meet at least semiannually within the Flathead basin, alternating the meeting site between the cities of Kalispell and Polson.

Section 8. Commission authority. (1) The commission may make recommendations to the legislature and the governor and to federal, tribal, provincial, and local agencies for maintenance and enhancement of the quality of natural resources of the Flathead basin.

(2) Subject to appropriation by the legislature, the commission may receive and expend donations, gifts, grants, and other money necessary to fulfill its duties.

Section 9. Establishment of account. There is established in the federal and private revenue fund a Flathead basin commission account. Money received by the Flathead basin commission under [section 8] and such other funds as are designated or appropriated for its use must be deposited in the account.

Section 10. Special county government authority. The governing body of any county within or bordering upon the Flathead basin may allocate to the Flathead basin commission a portion of any money available from coal severance tax allocations or other sources and designated for planning activities.

Section 11. Cooperation with other agencies and organizations. To fulfill its duties, the commission shall develop and maintain cooperative programs with federal, state, provincial, tribal, and local agencies or organizations that are responsible for natural resource management and monitoring in the Flathead basin. Participating federal and provincial agencies must be requested to provide adequate funds to participate on the commission and to monitor resources within their areas of responsibility.

Section 12. Initial terms of commission members. Five members of the original commission shall serve 2-year terms, thereby establishing staggered terms. Those members serving 2-year terms must be selected by lot at the first commission meeting.

Section 13. Effective date. This act is effective July 1, 1983.